CHAPTER 24
FUNGI

The study of fungi is MYCOLOGY

M.E.B.
Order Hymenomycetes.
Tribe Pileati.
Lactarius Indigo. Schw.
name – indigo, blue
Benjamin Cummings

Key Topics:

Evolution and Distinctive Features

Asexual and Sexual Reproduction

Diversity

Ecology and Biotechnology

Alija Mujic, Ph.D.
amujic@csufresno.edu

Evolution and Distinctive Features

Eukaryote supergroup **Opisthokonta**

- Includes some **protists,** the **Kingdom Animalia,** and **KINGDOM FUNGI**

Fungi are closely related to animals

- Both **heterotrophic** (no chlorophyll)
- Both use **absorptive nutrition** – secrete enzymes and absorb small organic molecules (fungi do it **outside** their bodies)
- Both store surplus food as the carbohydrate **glycogen**
- Both have eukaryotic cells and DNA wound around **histones**

Ecologically, fungi are decomposers, recycling nutrients in our ecosystem.

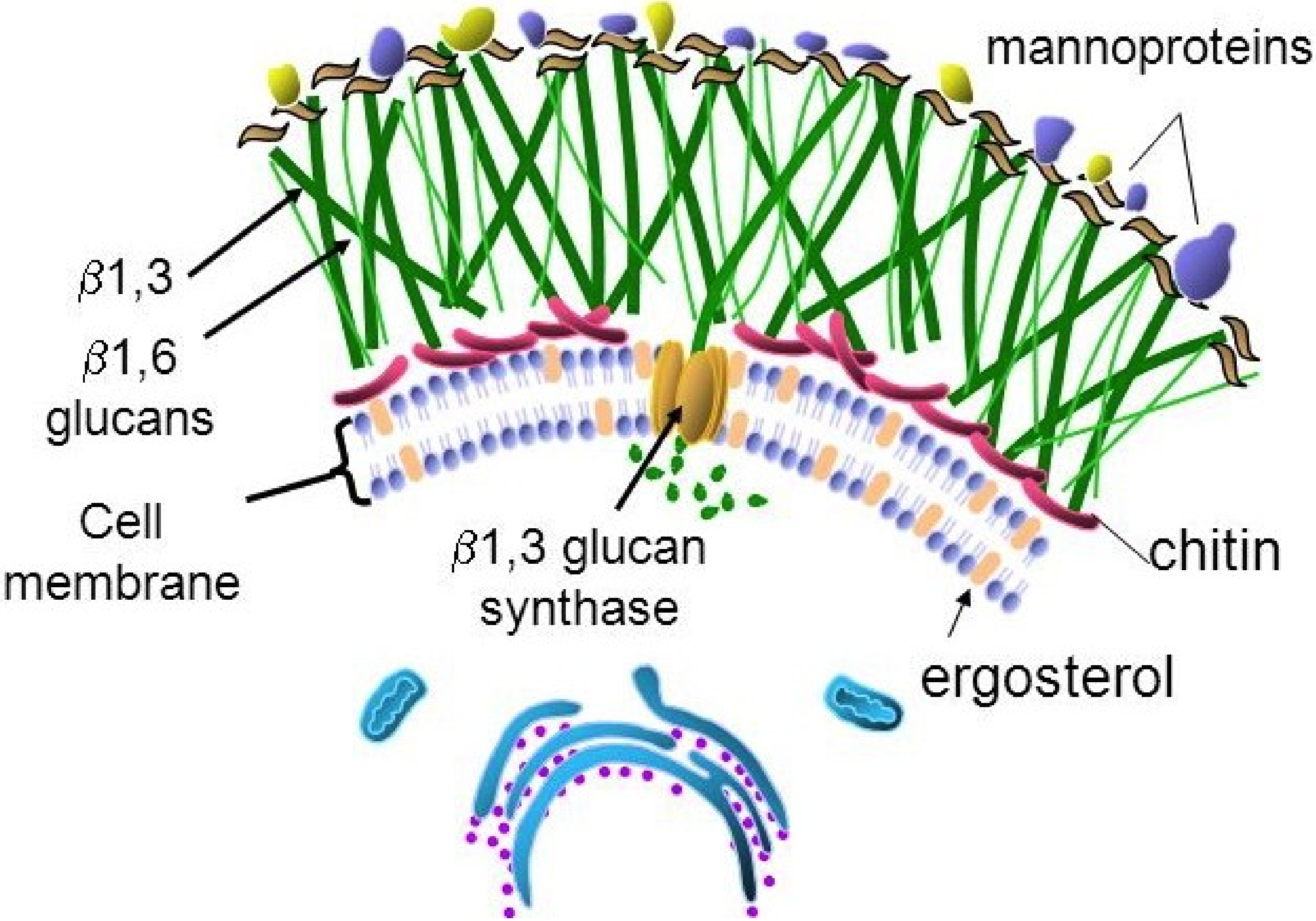
CHARACTERISTICS OF FUNGI

Non-motile eukaryotes lacking chlorophyll

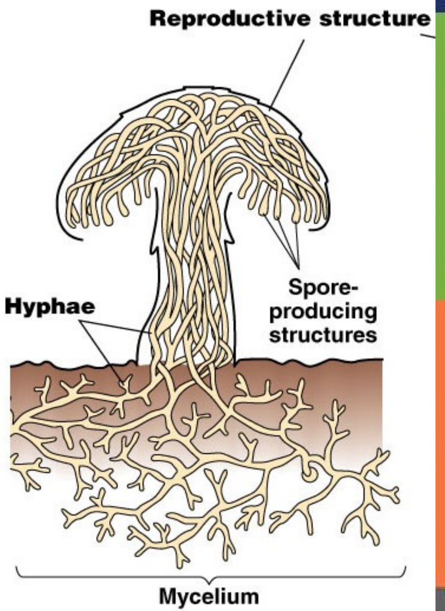
- Unicellular or multicellular depending on the species
- Single celled forms larger than bacteria.

- Plasma membrane contains **ergosterol** (a stabilizer in varying climates), instead of cholesterol.
- Cell wall is composed of **chitin** and various glucans (complex polysaccharides).
- Relatively simple nutritional requirements, wide range of growth rates
    - Form visible colonies in days to weeks

FUNGAL CELL WALL (YEAST)



UNIQUE BODY FORM



Copyright © Pearson Education, Inc., publishing as Benjamin Cummings.

Most have **mycelia** composed of **hyphae**

- Most of the mycelium is diffuse and inconspicuous

Many Fungi produce only yeast-like cells

- “yeast” refers to any fungus growing as a single cell and has no taxonomic meaning.
- Some fungi are capable of switching between a mycelial and yeast growth form and these are known as **dimorphic.**

Fruiting bodies (sporocarps) – visible reproductive structures

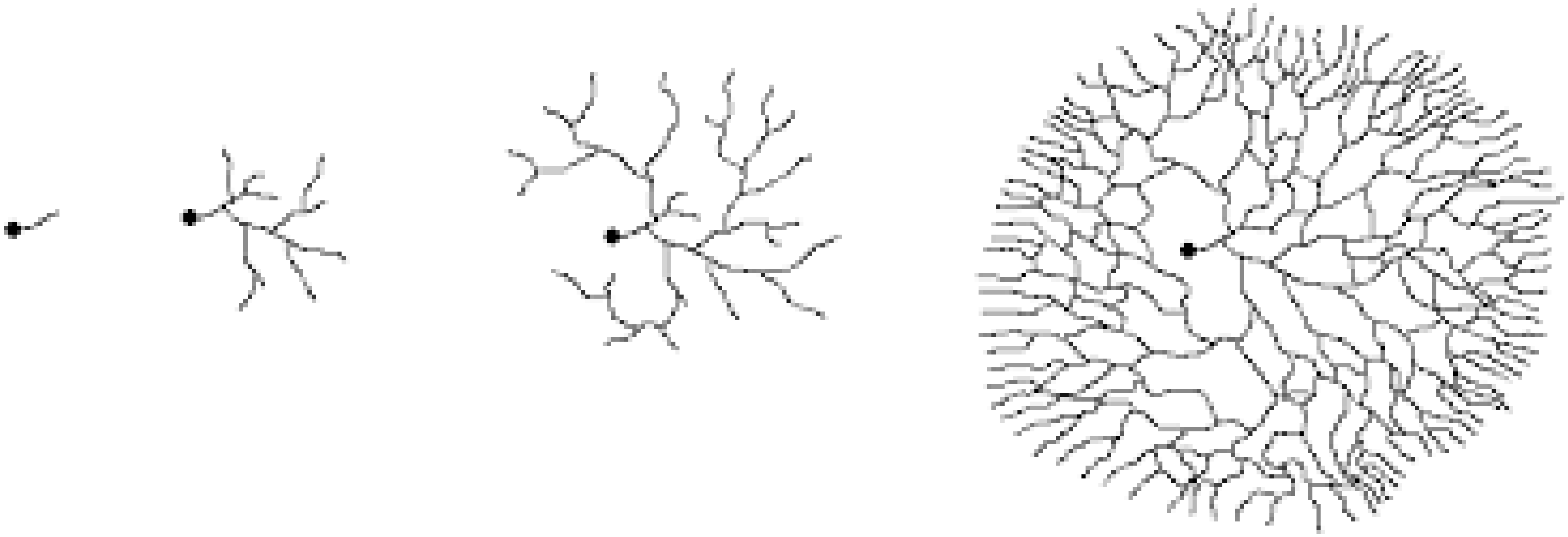
- Mushrooms are one type
- Produce spores

DISTINCTIVE GROWTH PROCESSES

Mycelia can grow quickly when food is plentiful

Hyphae grows only at their tips.

Narrow dimensions and extensive branching of hyphae provides **high surface area for absorption**



Fungal Asexual and Sexual Reproduction

Many fungi reproduce by **microscopic spores** that grow into a new organism

- Spores may be asexual clones
- Or from sexual reproduction with new allele combinations

Asexual reproduction is ideal for **rapid spread**

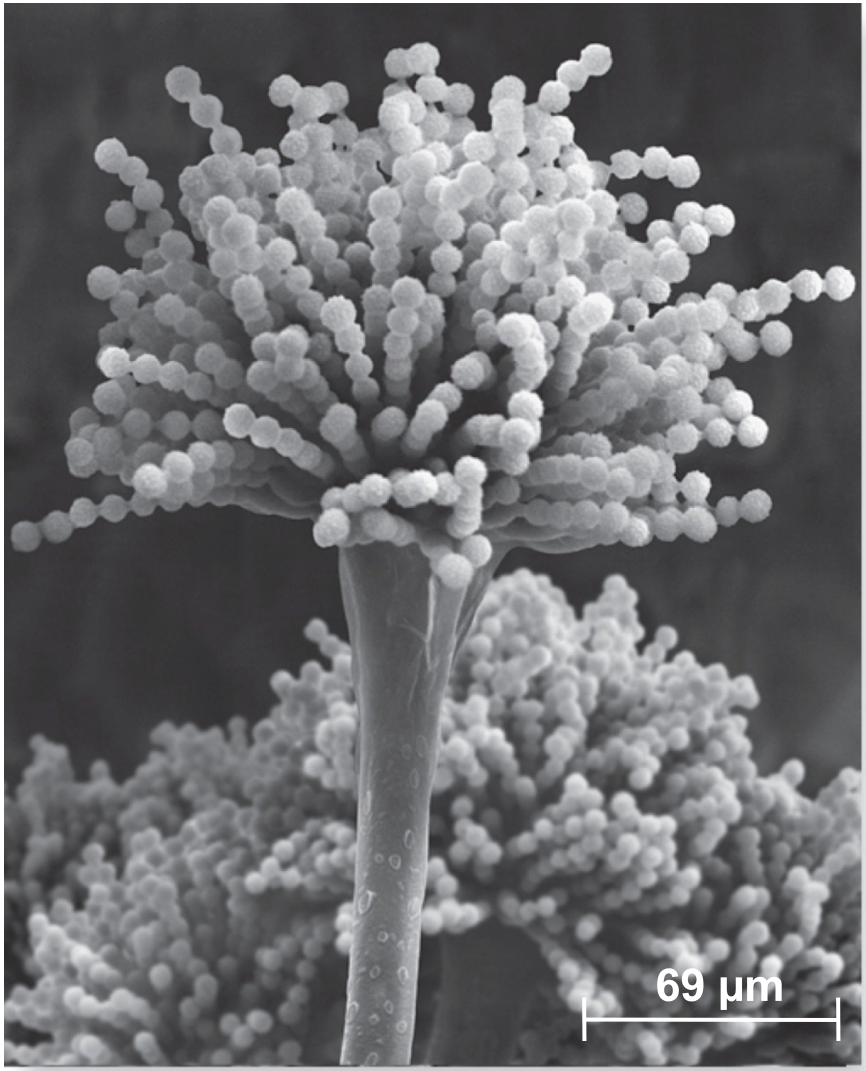
- No need to find a mate
- No fruiting body
- No meiosis (mycelium is already haploid)

Conidia

- Asexual spores grown at the tips of hyphae

Aspergillus versicolor

- Causes skin and lung infections in vulnerable patients
- It can be found in arctic regions as well as in the Mir space station and the Dead Sea.



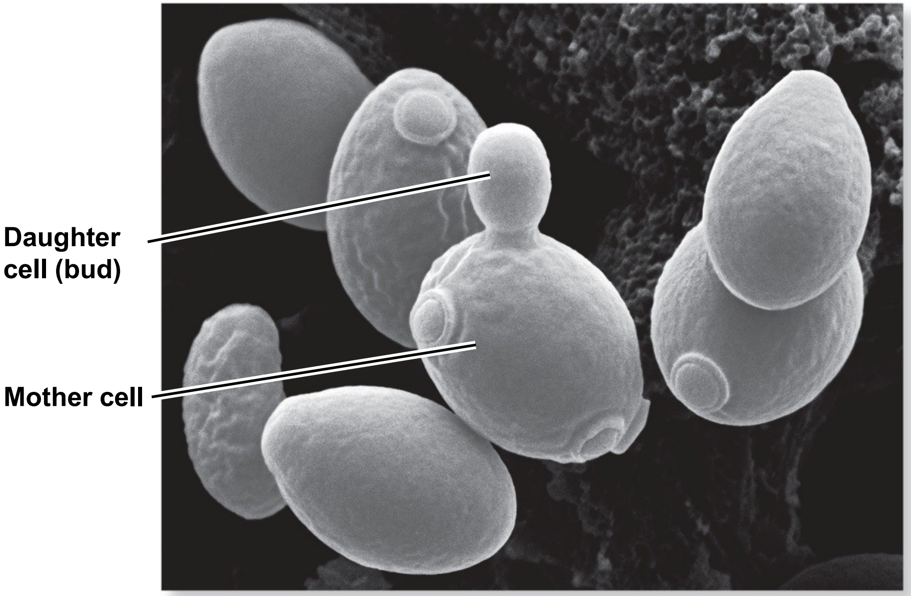
© Dr. Dennis Kunkel Microscopy/ Visuals Unlimited

Medically important fungi that reproduce primarily by asexual means include

- **Athlete's foot fungus** (*Epidermophyton floccosum)*
- **Infectious yeast** *(Candida albicans)*

Budding yeast, ***Saccharomyces cerevisiae***

- Can reproduce either sexually or by asexual budding



© Medical-on-Line/Alamy

SEXUAL REPRODUCTION

Involves union of gametes, zygote formation and meiosis

Gametes of most fungi are cells from branches of the hyphae

- **+/- Mating types may** differ biochemically
- Hyphal branches fuse between compatible mating types

Most sexual organisms have **plasmogamy** (fusion of gametes' cytoplasm) followed by **karyogamy** (fusion of gametes' nuclei)

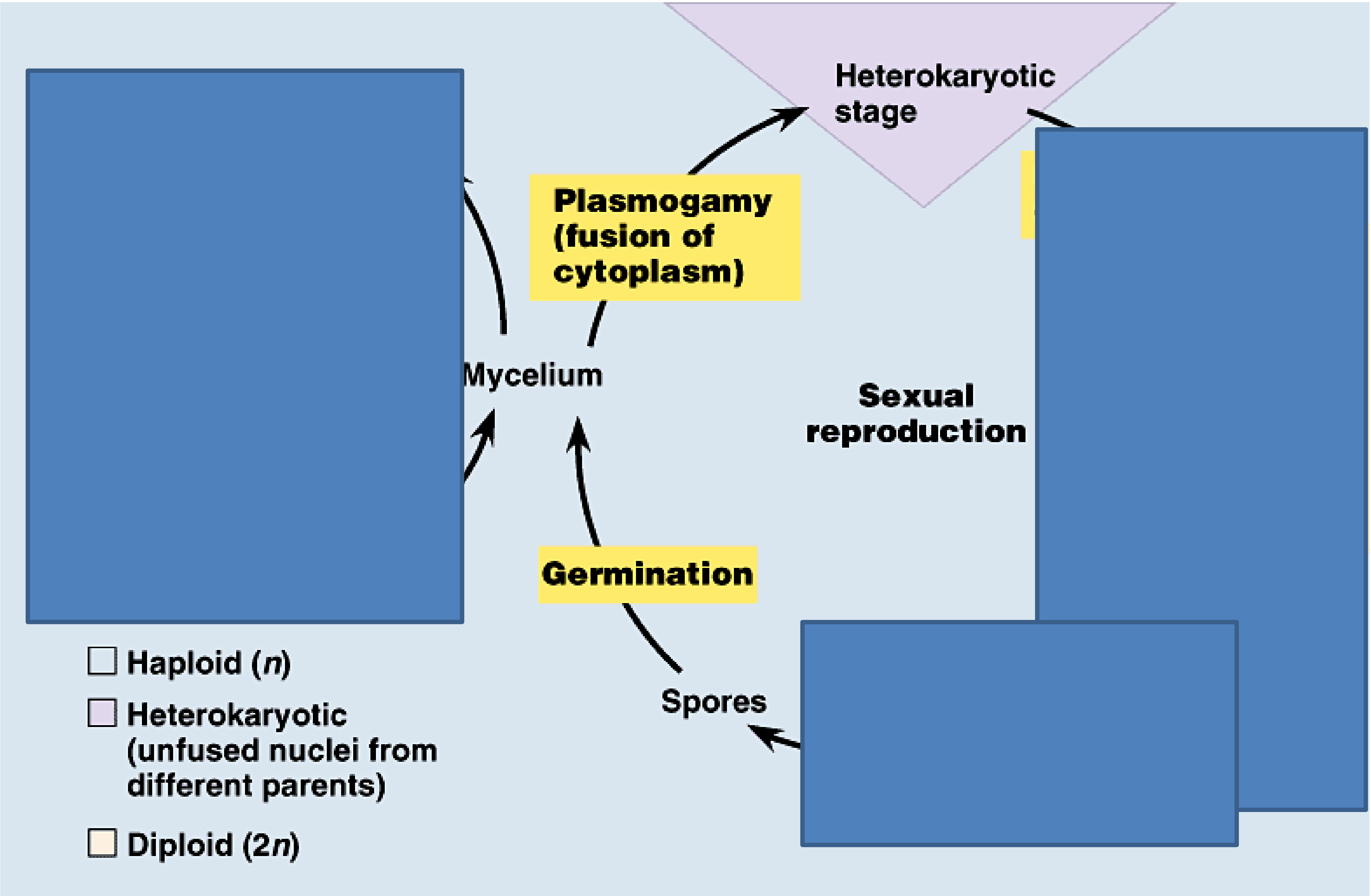
In many fungi, after plasmogamy, nuclei may remain separate for a long time

  - This mycelium is **dikaryotic** or **heterokaryotic (2 or more nuclei in same cell but not fused)**

Some fungi persist as **dikaryons,** producing clones that can live for hundreds of years

  - Eventually, dikaryotic mycelia produce fruiting bodies, the next stage of reproduction

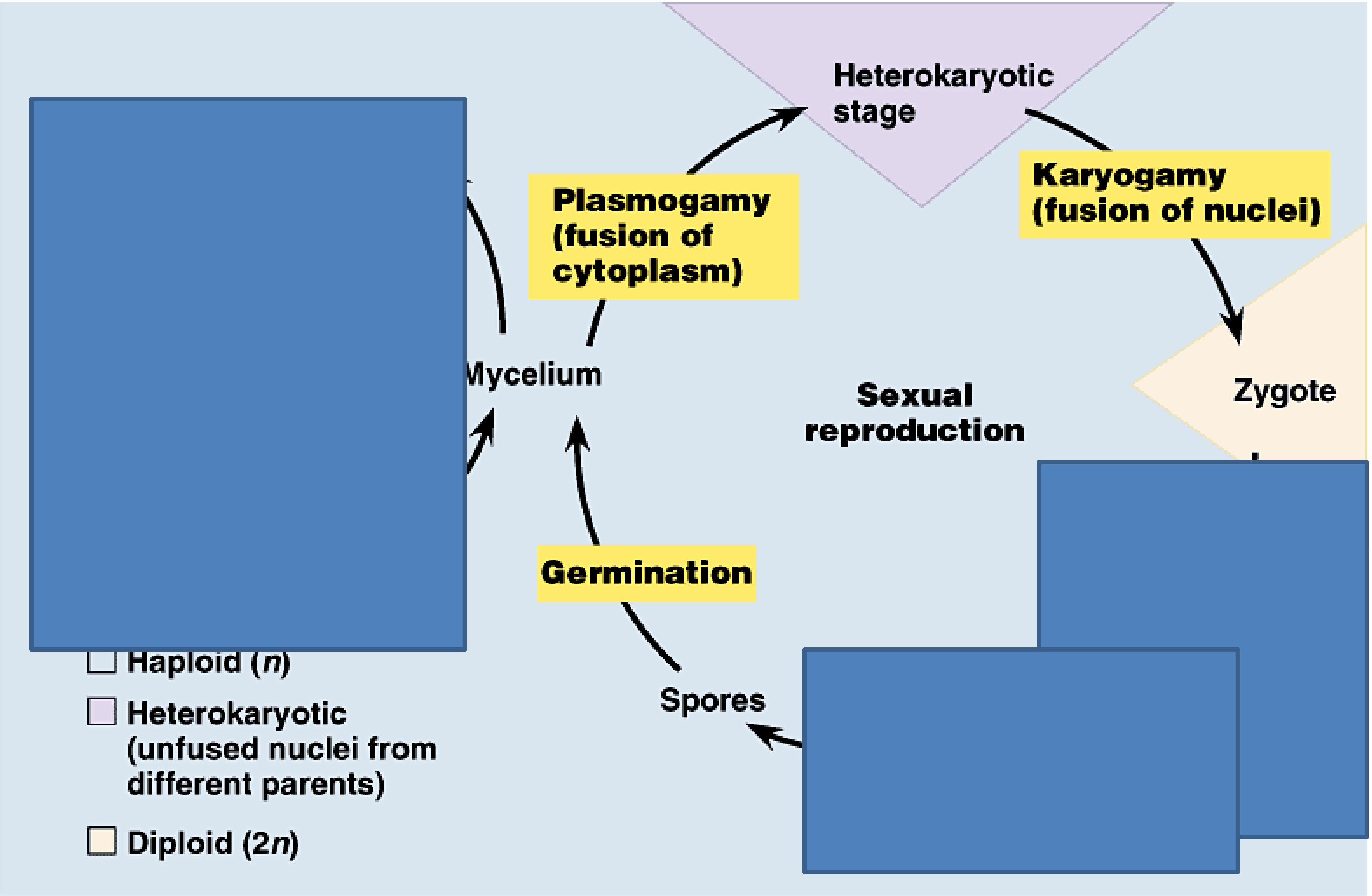
GENERALIZED LIFE CYCLE OF FUNGI



- ☐ Haploid (*n*)
- ☐ Heterokaryotic (unfused nuclei from different parents)
- ☐ Diploid (2*n*)

Copyright © Pearson Education, Inc., publishing as Benjamin Cummings.

GENERALIZED LIFE CYCLE OF FUNGI



Heterokaryotic stage

Plasmogamy (fusion of cytoplasm)

Karyogamy (fusion of nuclei)

Mycelium

Sexual reproduction

Zygote

Germination

Spores

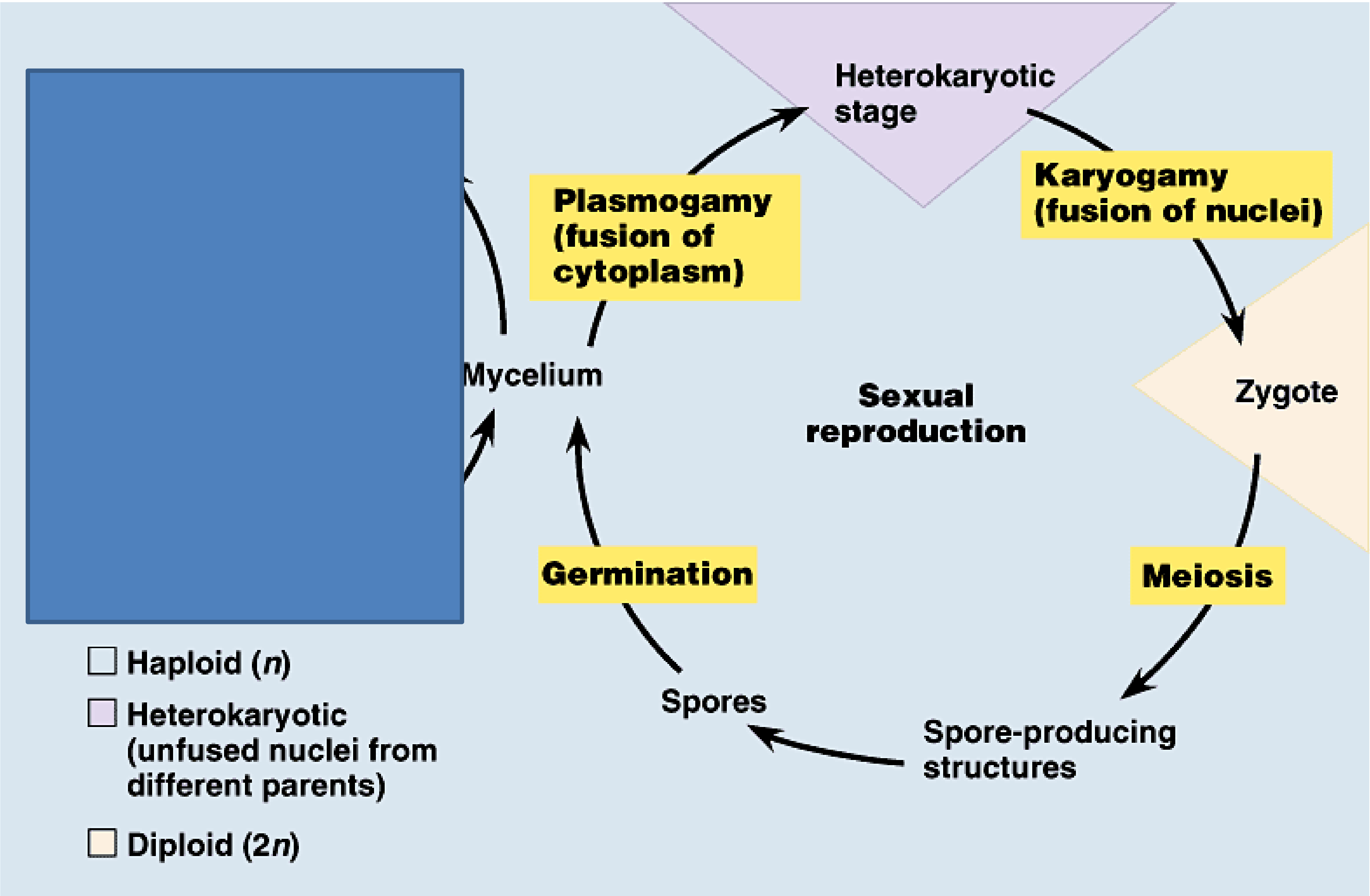
☐ Haploid (*n*)

☐ Heterokaryotic (unfused nuclei from different parents)

☐ Diploid (2*n*)

Copyright © Pearson Education, Inc., publishing as Benjamin Cummings.

GENERALIZED LIFE CYCLE OF FUNGI



Heterokaryotic
stage
Plasmogamy (fusion of cytoplasm)
Karyogamy (fusion of nuclei)
Mycelium
Zygote
Sexual reproduction
Germination
Meiosis
Spores
Spore-producing structures

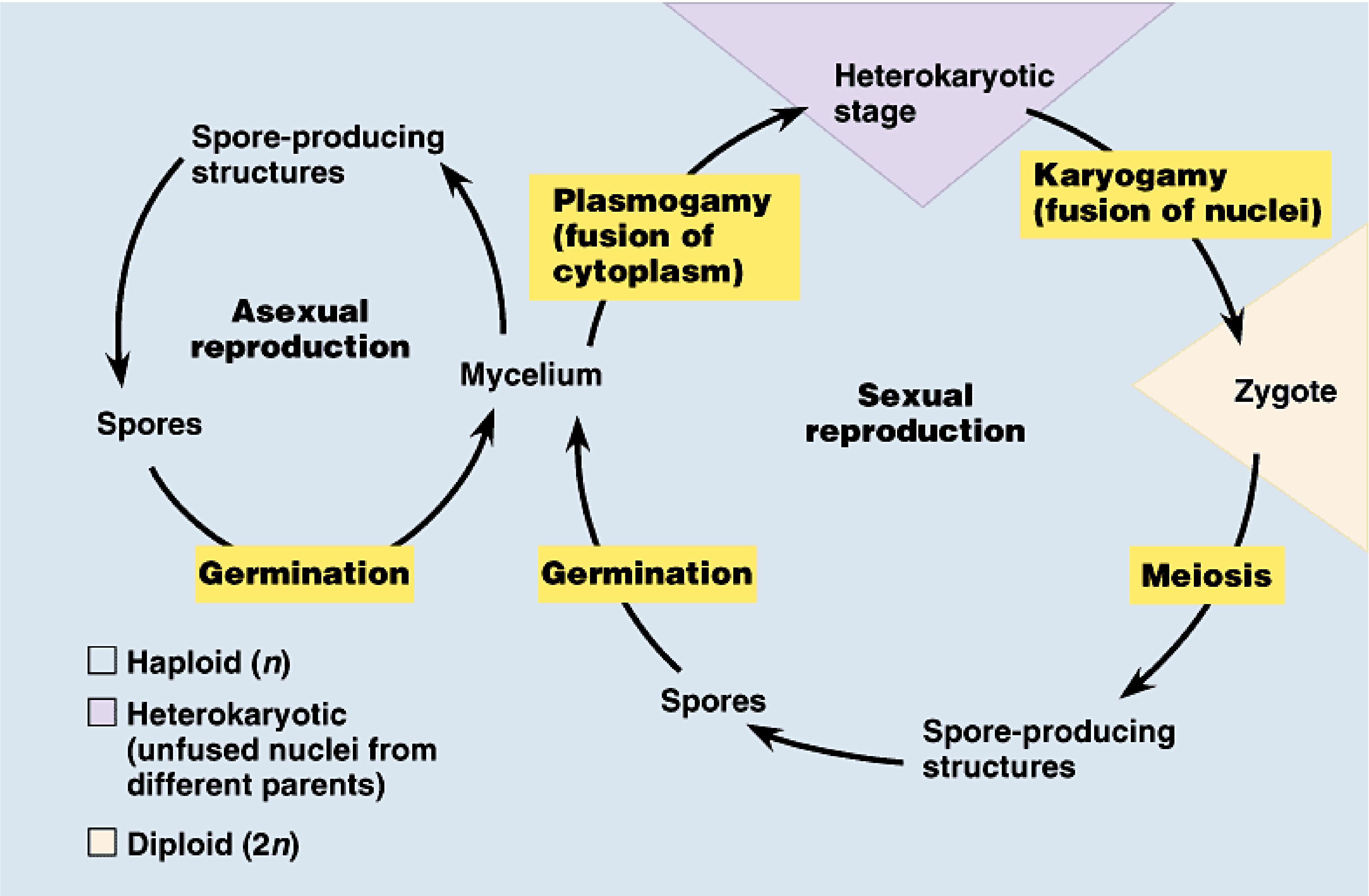
☐ Haploid (*n*)

🟪 Heterokaryotic (unfused nuclei from different parents)

🟨 Diploid (2*n*)

Copyright © Pearson Education, Inc., publishing as Benjamin Cummings.

GENERALIZED LIFE CYCLE OF FUNGI



Heterokaryotic stage

Plasmogamy (fusion of cytoplasm)

Karyogamy (fusion of nuclei)

Spore-producing structures

Asexual reproduction

Mycelium

Zygote

Spores

Sexual reproduction

Germination

Germination

Meiosis

Spores

Spore-producing structures

☐ Haploid (*n*)

☐ Heterokaryotic (unfused nuclei from different parents)

☐ Diploid (2*n*)

Copyright © Pearson Education, Inc., publishing as Benjamin Cummings.

FRUITING BODIES

Dikaryotic mycelium may produce a fleshy fruiting body (like a mushroom)

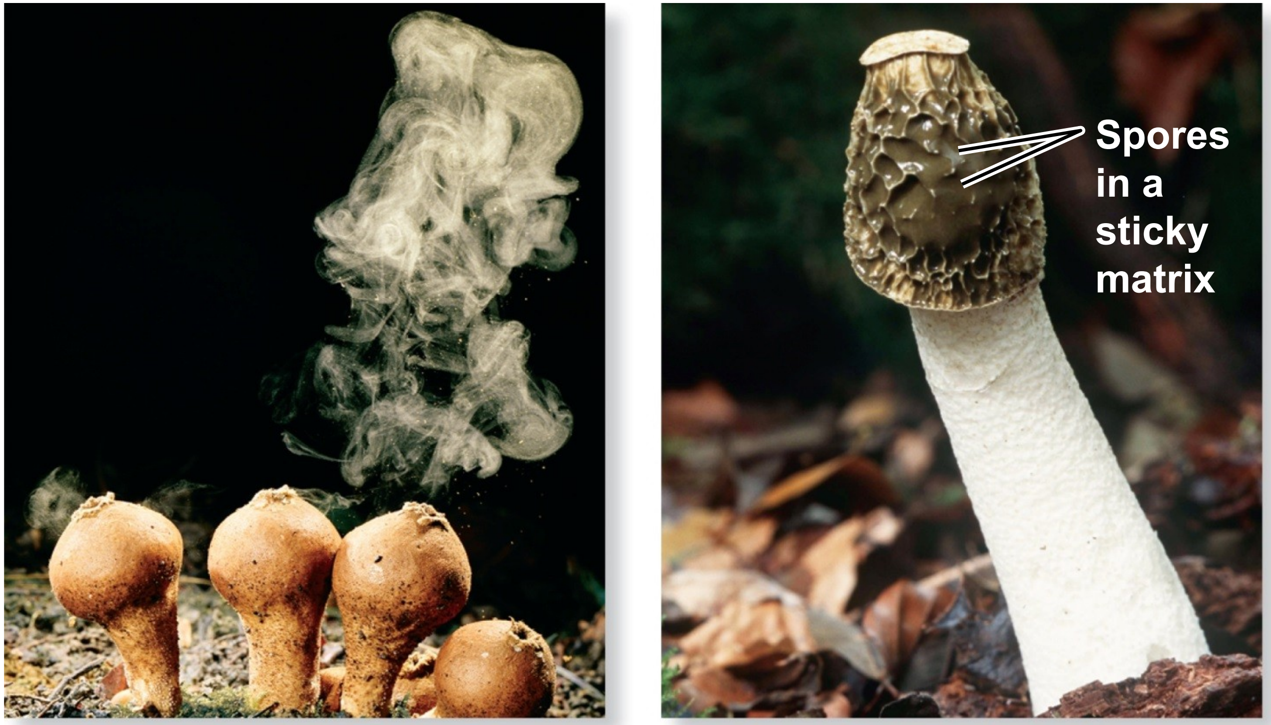
All cells of the fruiting body are dikaryotic.

When mature, the two nuclei in cells will fuse.

Produces zygotes (**the only diploid stage**)

Undergo meiosis to produce haploid spores for dispersal

Structure of fruiting bodies varies in ways that reflect adaptations for spore dispersal by wind, rain or animals



(a) Fruiting bodies adapted for dispersal of spores by wind

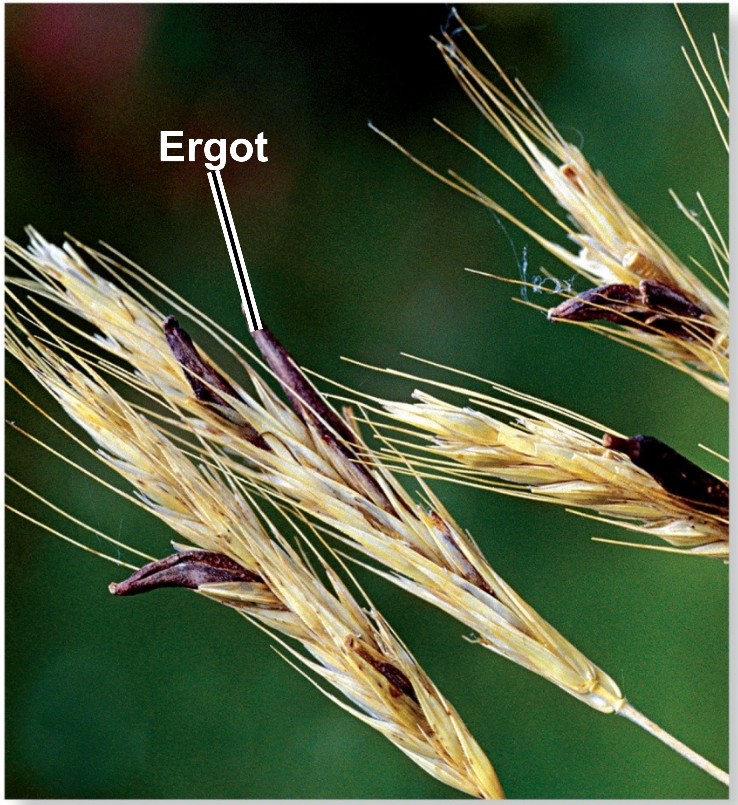
(b) Fruiting body adapted for dispersal of spores by insects

a: © Felix Labhardt/Taxi/Getty Images; b: © Bob Gibbons/ardea.com

Many fungi produce substances in the fruiting body to deter consumption or affect host physiology

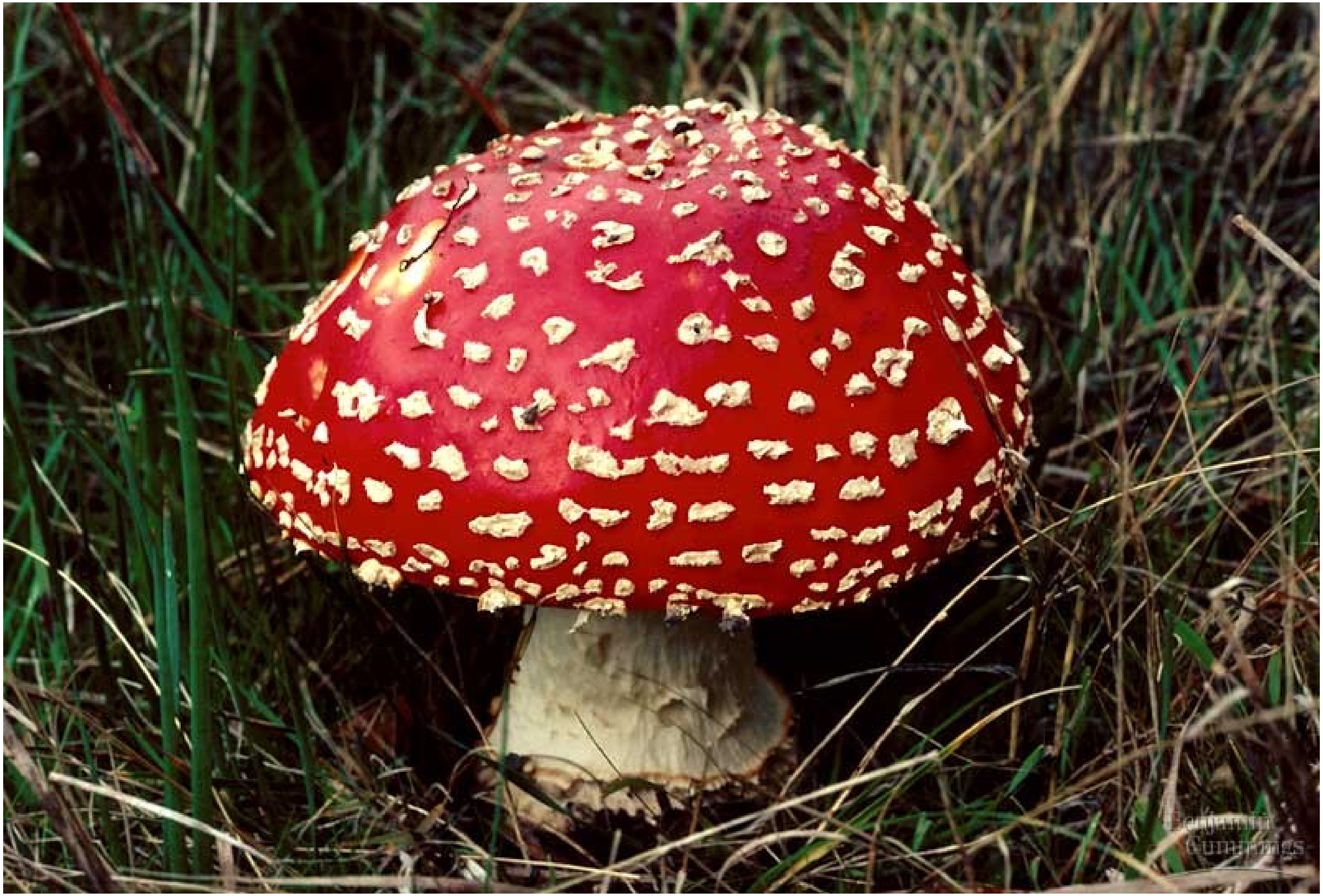
- ☐ Toxins can cause inhibition of mRNa synthesis and eventual multiple organ failure
- ☐ Hallucinogenic or psychoactive substances
- ☐ Toxins can affect host insect behaviors

© Gary Meszaros/Visuals Unlimited



© David Q. Cavagnaro/Getty Images

AMANITA SP. (FLY AGARIC) – THE MARIO SUPER MUSHROOM POWERUP! SOME SPECIES ARE HALLUCINOGENIC

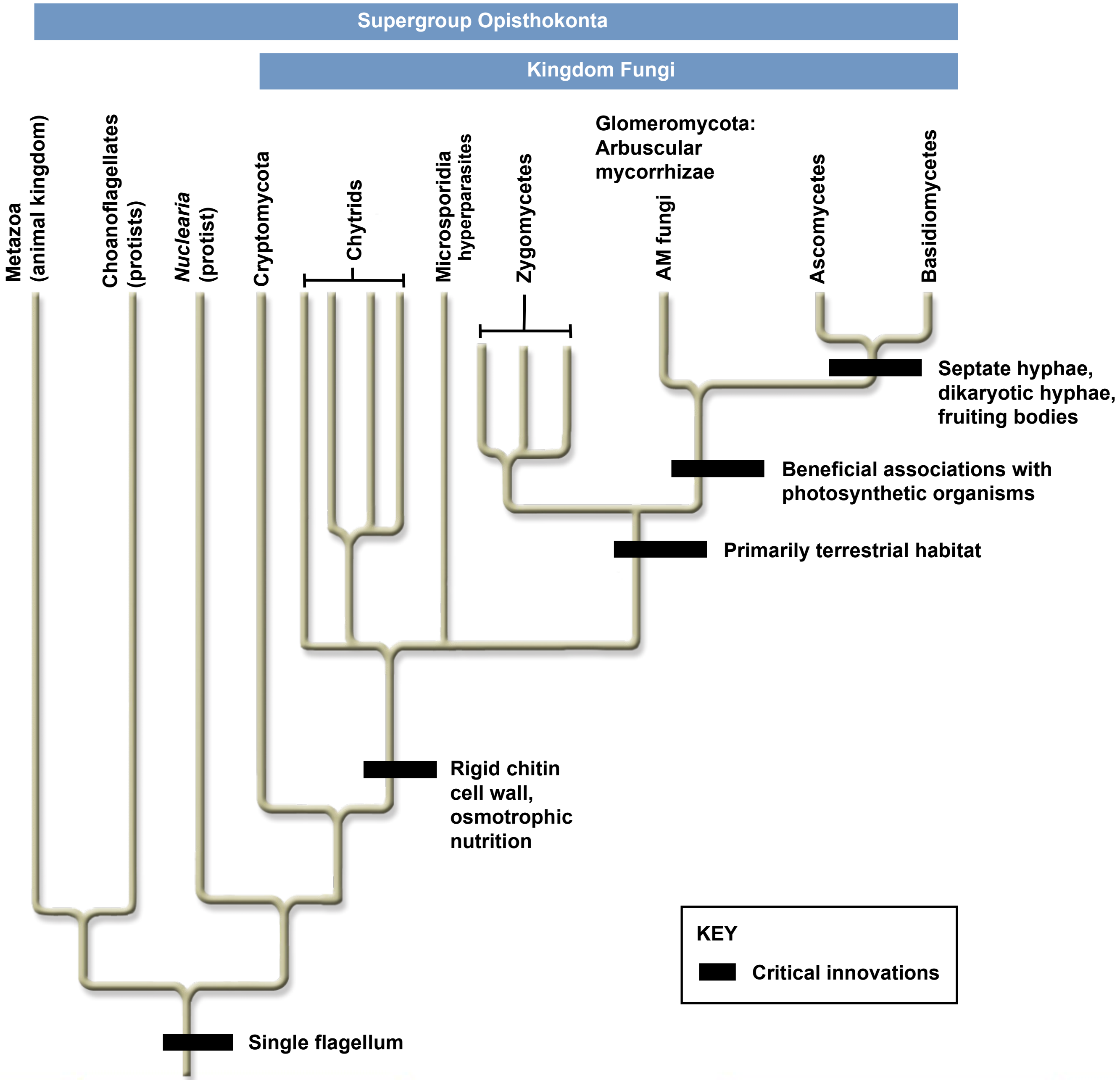


Benjamin Cummings

Diversity of Fungi

Fungal Phyla (we will only discuss a few here today)

- Cryptomycota (Sister group to fungus – no chitin or cell walls)
- **Microsporidia**
- **Chytridiomycota**
- (Blastocladiomycota)
- **Mucoromycota** (“Zygomycetes”)
- Zoopagomycota (“Zygomycetes”)
- **Ascomycota**
- **Basidiomycota**
- **Glomeromycota (AM fungus)**



Supergroup Opisthokonta

Kingdom Fungi

Metazoa (animal kingdom)

Choanoflagellates (protists)

***Nuclearia* (protist)**

Cryptomycota

Chytrids

Microsporidia hyperparasites

Zygomycetes

Glomeromycota: Arbuscular mycorrhizae

AM fungi

Ascomycetes

Basidiomycetes

Septate hyphae, dikaryotic hyphae, fruiting bodies

Beneficial associations with photosynthetic organisms

Primarily terrestrial habitat

Rigid chitin cell wall, osmotrophic nutrition

Single flagellum

KEY

Critical innovations

PHYLUM MICROSPORIDIA

Named for their **very small size** (1–4 μm) and occurrence as **single-celled spores**

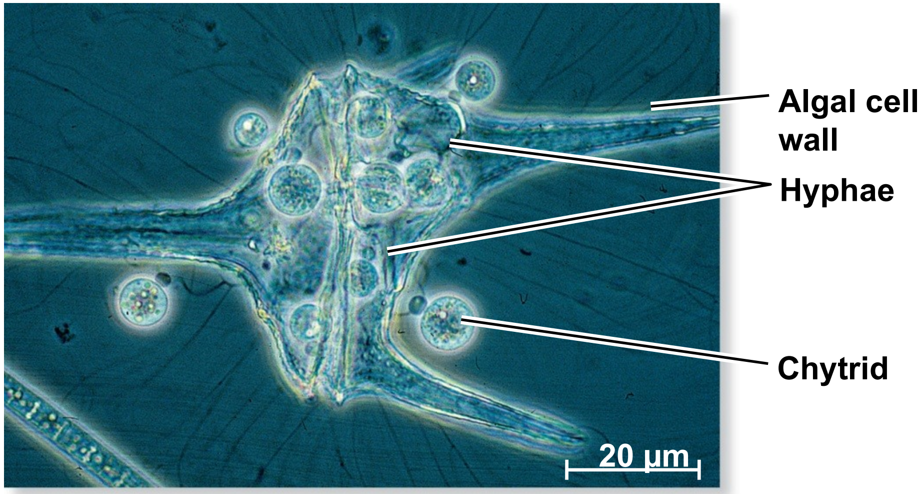
Pathogens that can only reproduce in an animal host

Chitin protects spores when transferring between animals

Contain a coiled threadlike structure that helps them **invade animal cells**

ex: ***Nosema ceranae*** – linked to honeybee colony collapse disorder, in conjunction with an RNA virus

CHYTRIDS (PHYLUM CHYTRIDIOMYCOTA)



© Photograph by H. Cantor-Lund reproduced with permission of the copyright holder J. W. G. Lund

Live in water or moist soil

Have a rigid chitin cell wall

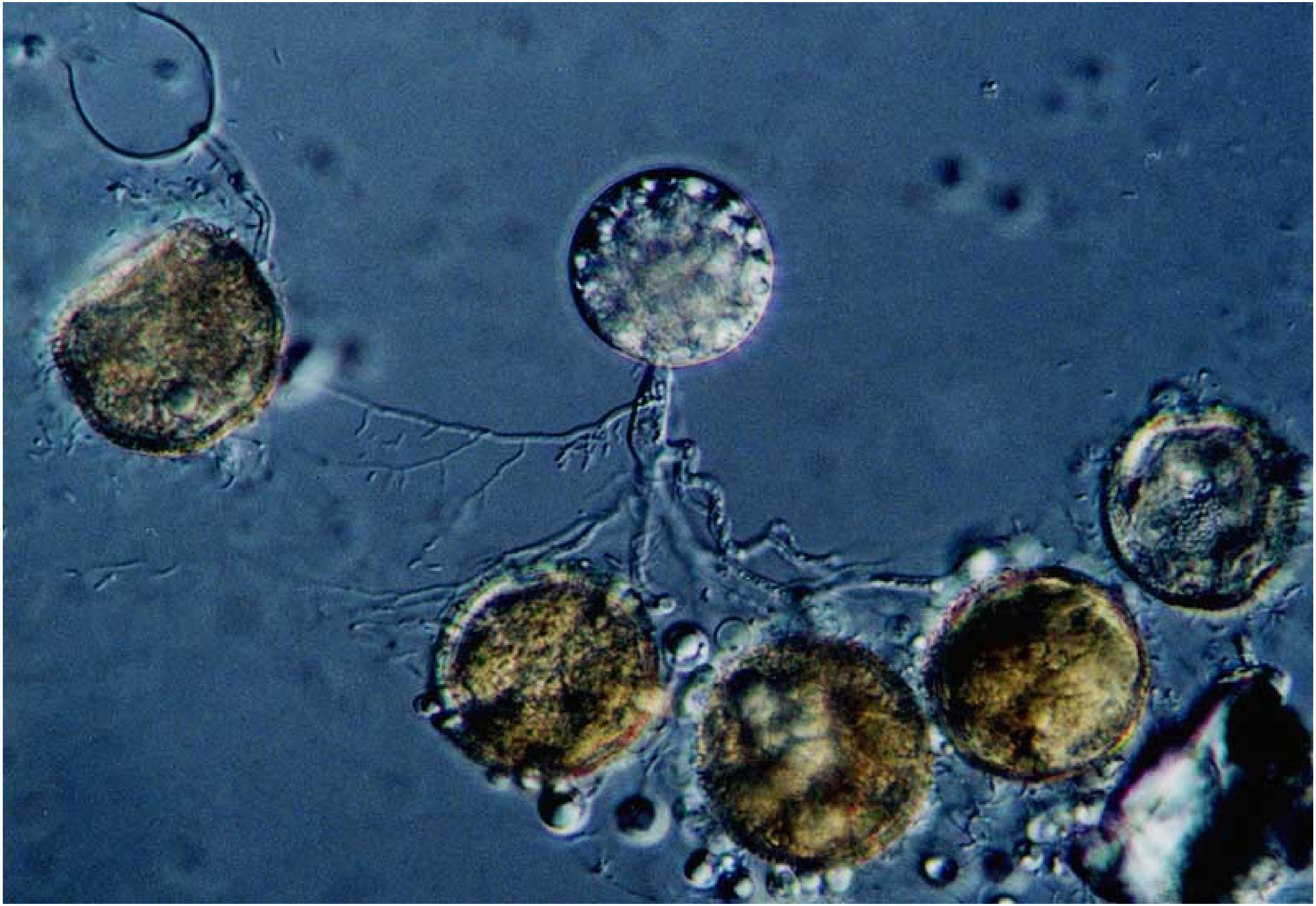
Some are single, spherical cells that may produce hyphae

Most are decomposers, but some are parasites or pathogens

ex: ***Batrachochytrium dendrobatidis***

- associated with declining frog populations

CHYTRIDIOMYCOTA (CHYTRIDS)



MUCOROMYCOTA (“ZYGOMYCETES”)

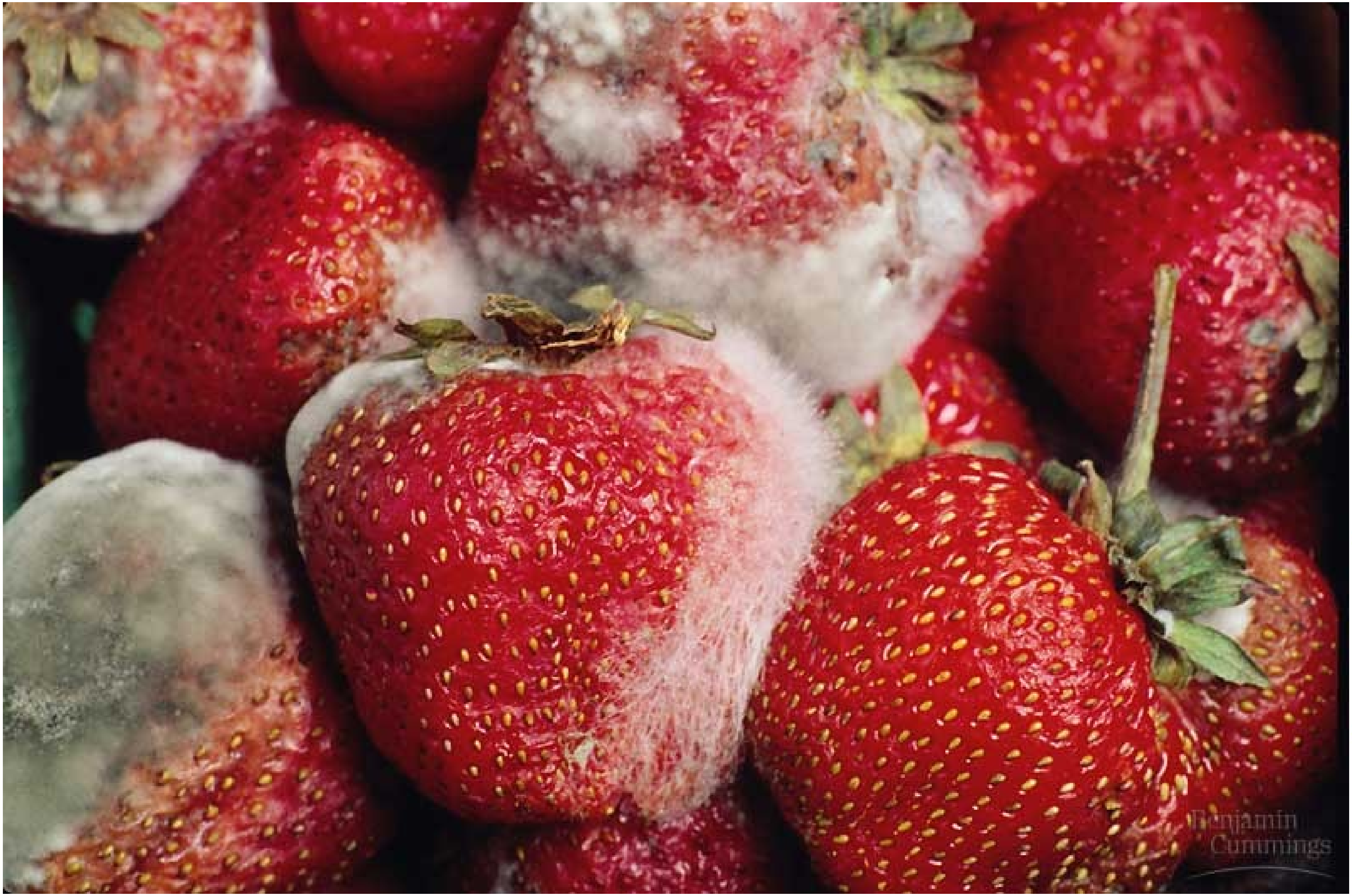
Most decomposers, but some are parasites

Mycelium composed of aseptate hyphae and distinctive reproductive structures

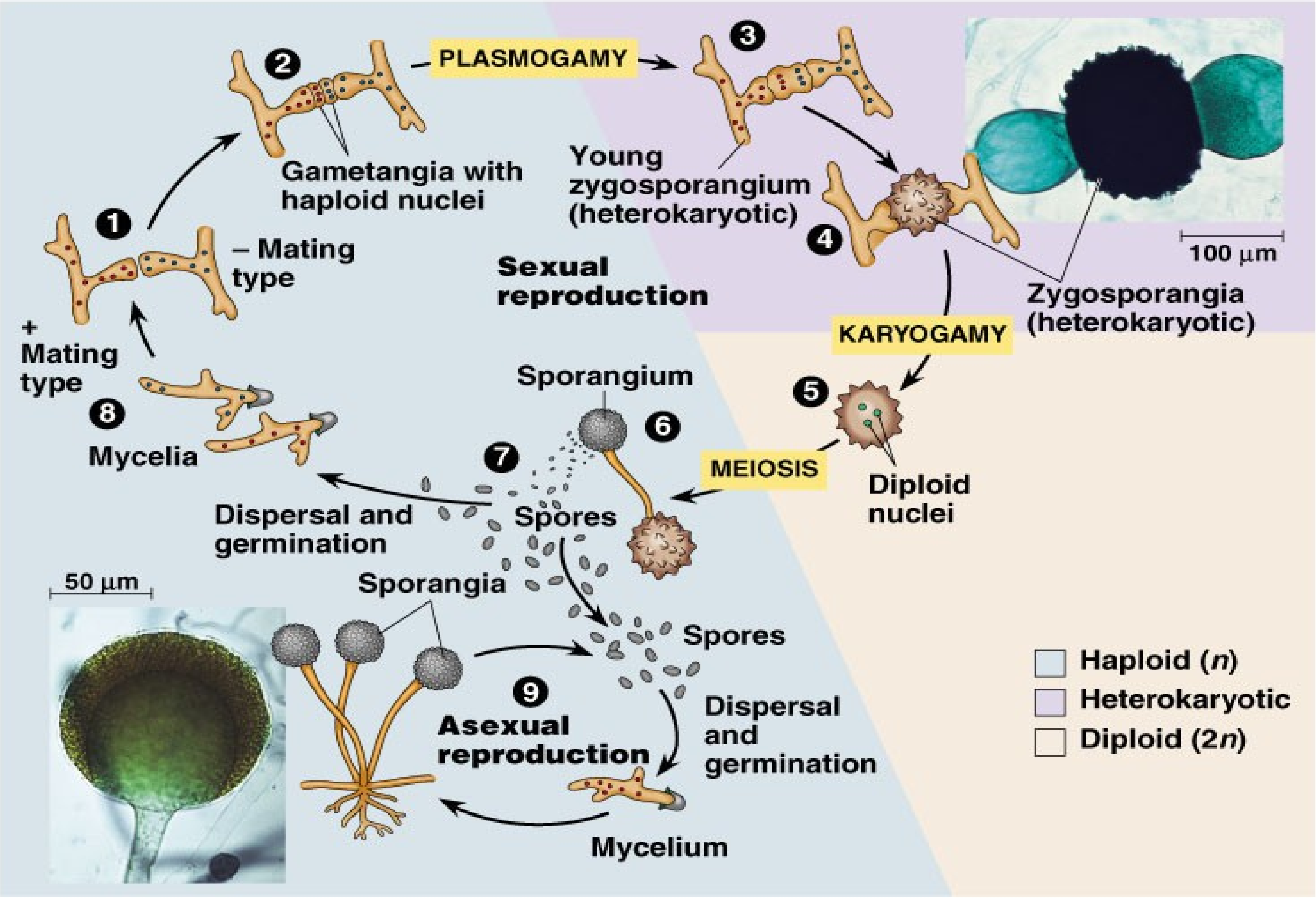
ex: **black bread mold** *Rhizopus stolonifer*

- **Asexual spores** in dark-pigmented enclosures known as sporangia that can release 100,000 spores each
- **Sexual reproduction** uses distinctive **zygospore**
  - Gametangia of compatible mating types fuse, producing a zygosporangium
  - A multinucleate zygospore matures in each zygosporangium
  - Haploid nuclei fuse in pairs, producing diploid nuclei
  - Later, these undergo meiosis to produce haploid spores

THE COMMON MOLD *RHIZOPUS* DECOMPOSING STRAWBERRIES

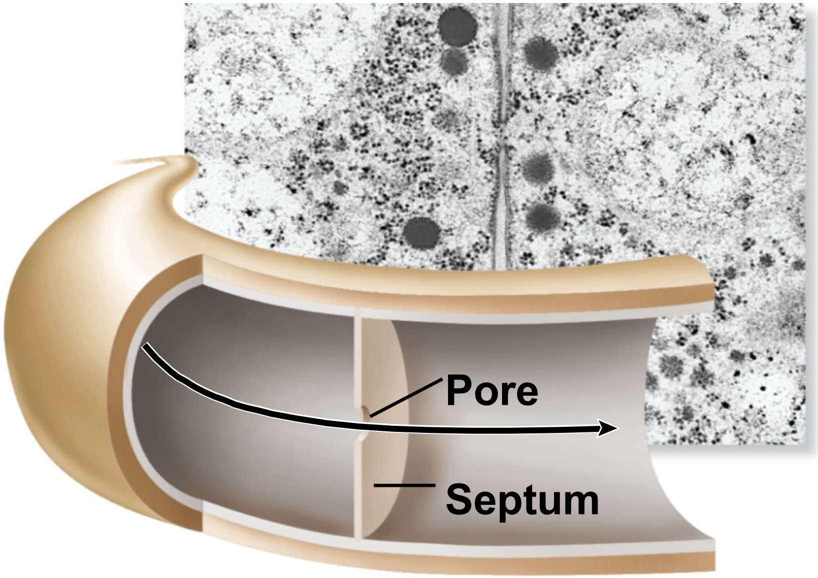


THE LIFE CYCLE OF THE ZYGOMYCETE *RHIZOPUS STOLONIFER* (BLACK BREAD MOLD)



Copyright © Pearson Education, Inc., publishing as Benjamin Cummings.

ASCOMYCOTA (SAC FUNGI)



(a) Simple pore—ascomycetes

a: Micrograph courtesy of Timothy M. Bourett, DuPont Crop Genetics, Wilmington, DE USA

Hyphae subdivided by septa with simple pores

Meiosis occurs in sack-like cells called **asci**

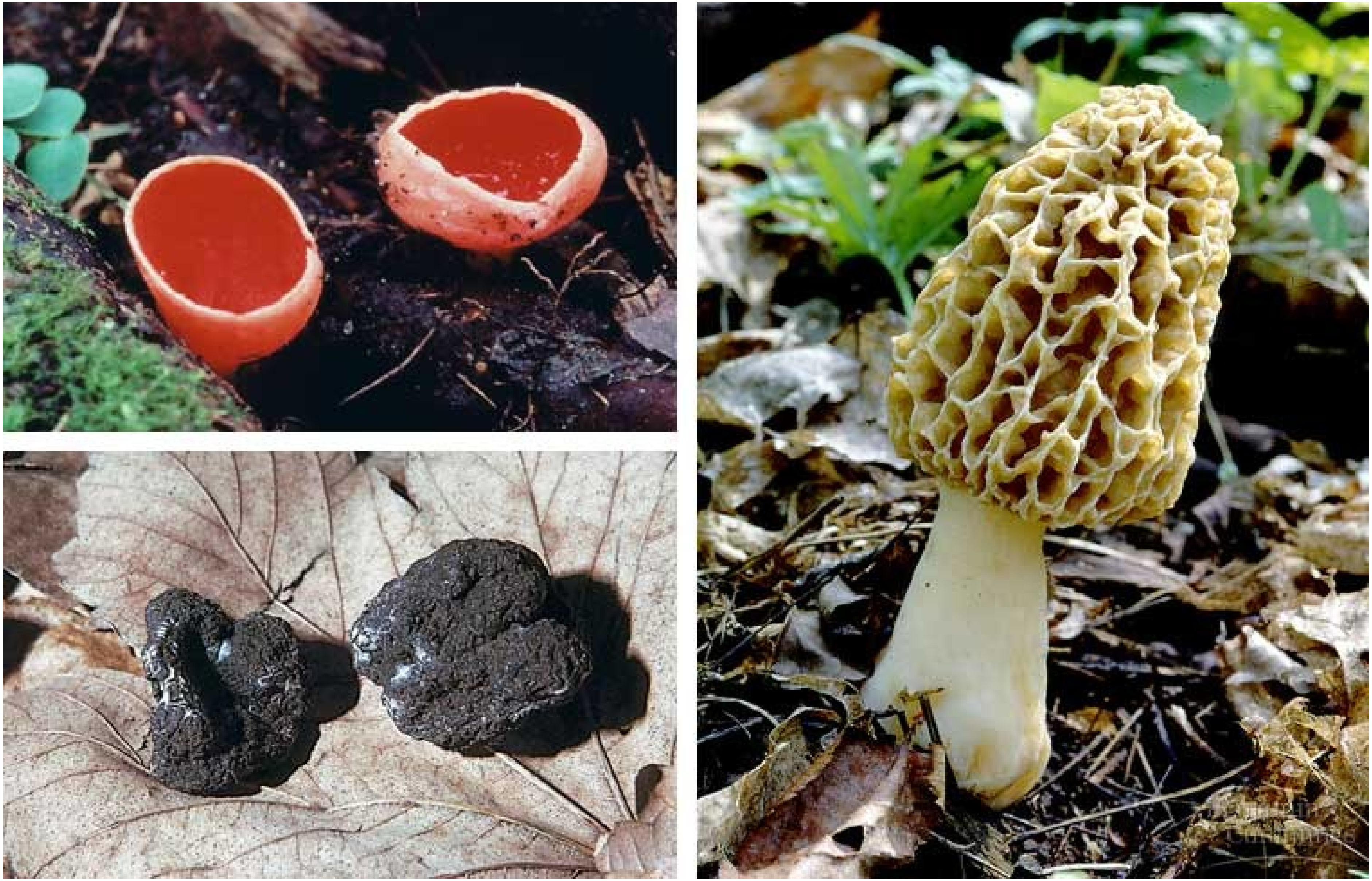
  - Produce sexual spores called ascospores
  - Asci produced on fruiting bodies called ascocarps

Occur in terrestrial and aquatic habitats

Include decomposers, plant and animal pathogens, and mutualists

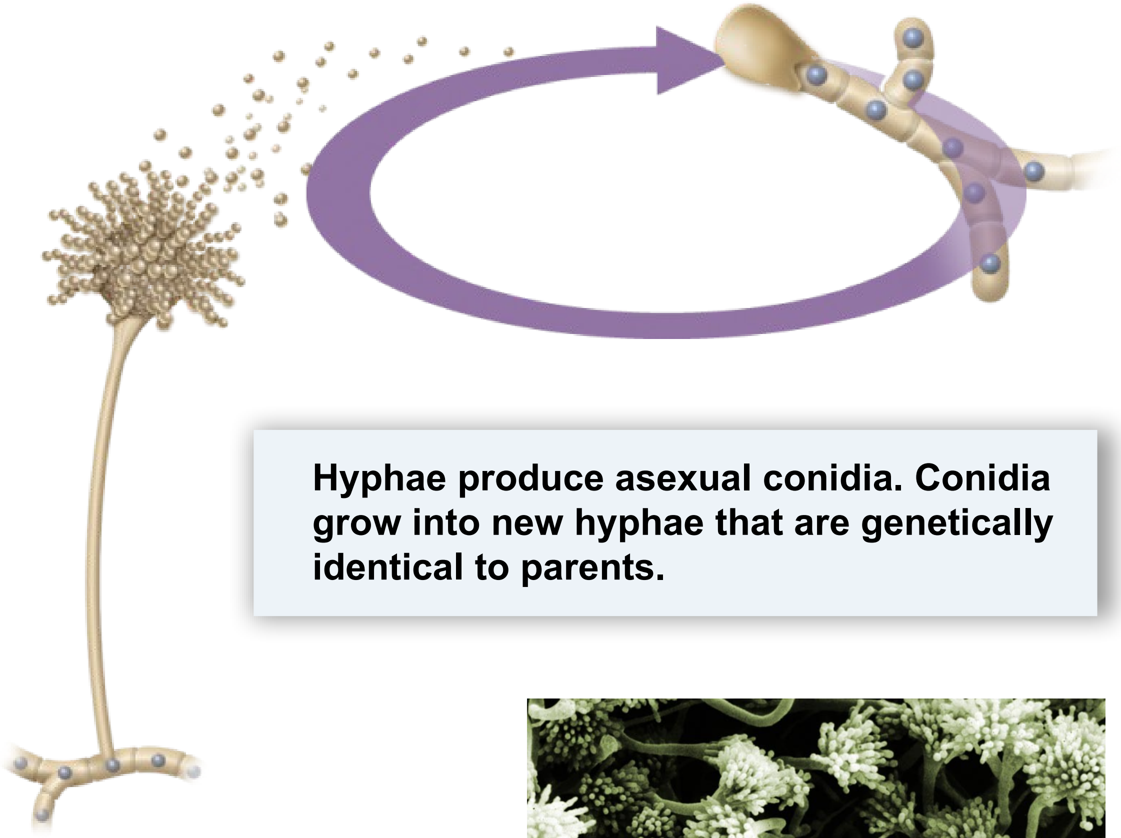
  - Including powdery mildews, chestnut blight, Dutch elm disease, and apple scab

ASCOMYCETES (SAC FUNGI): SCARLET CUP (TOP LEFT), TRUFFLES (BOTTOM LEFT), MOREL (RIGHT)



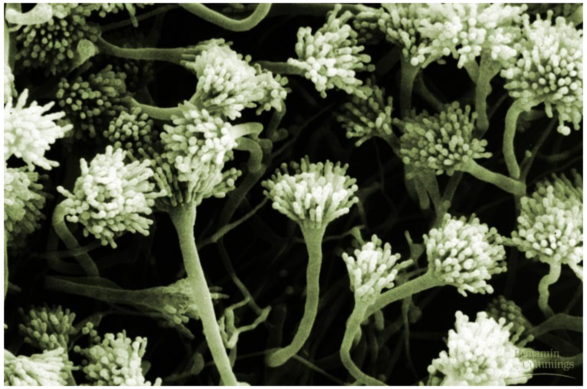
Black truffles - *Tuber melanosporum:* market price ~ $1,200 per lb. (€ 2,000 per kg)

© Nacivet/Getty Images



Hyphae produce asexual conidia. Conidia grow into new hyphae that are genetically identical to parents.

(a) Asexual reproduction



ASPERGILLUS

KEY

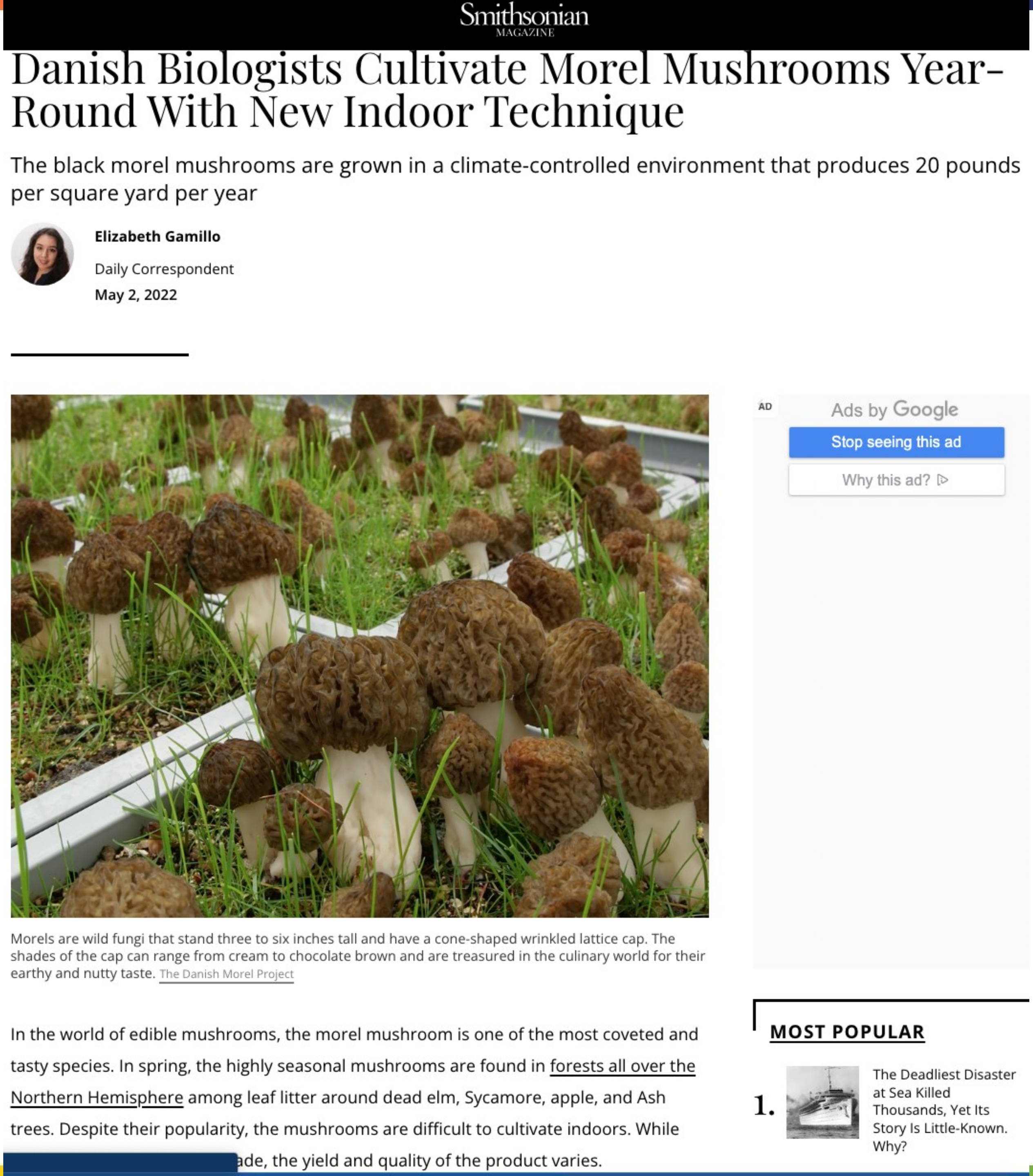
🟪 Haploid

🟦 Diploid

🟥 Heterokaryotic

https://www.smithsonianmag.com/smart-news/danish-biologists-find-technique-to-cultivate-morel-mushrooms-year-round-180980007/

$50/lb fresh
$200/lb dry
20lbs mushrooms per square yard



Smithsonian
MAGAZINE

Danish Biologists Cultivate Morel Mushrooms Year-Round With New Indoor Technique

The black morel mushrooms are grown in a climate-controlled environment that produces 20 pounds per square yard per year

Elizabeth Gamillo

Daily Correspondent

May 2, 2022

Morels are wild fungi that stand three to six inches tall and have a cone-shaped wrinkled lattice cap. The shades of the cap can range from cream to chocolate brown and are treasured in the culinary world for their earthy and nutty taste. The Danish Morel Project

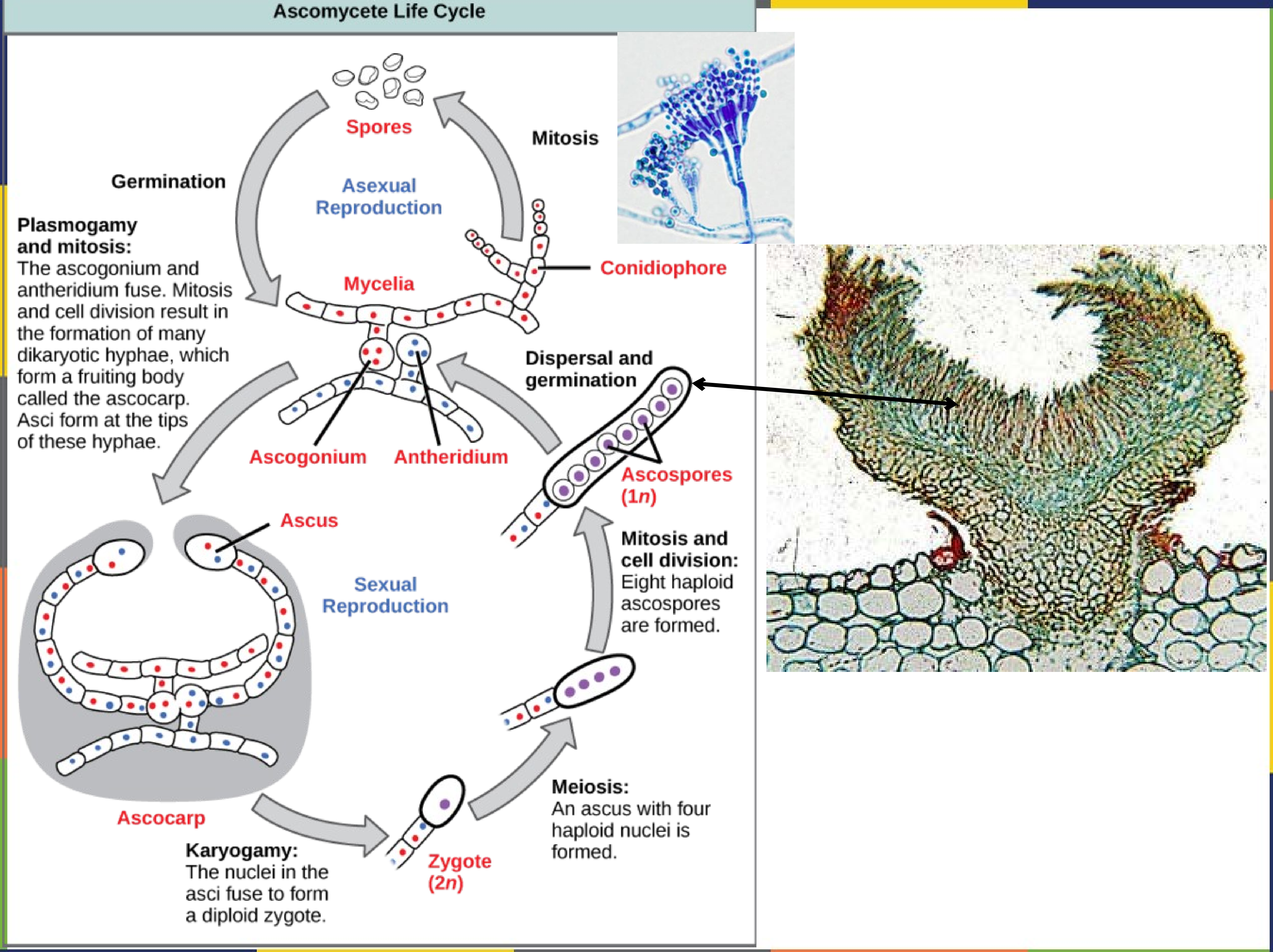
AD Ads by Google
Stop seeing this ad
Why this ad? ▷

In the world of edible mushrooms, the morel mushroom is one of the most coveted and tasty species. In spring, the highly seasonal mushrooms are found in forests all over the Northern Hemisphere among leaf litter around dead elm, Sycamore, apple, and Ash trees. Despite their popularity, the mushrooms are difficult to cultivate indoors. While ade, the yield and quality of the product varies.

MOST POPULAR

1. The Deadliest Disaster at Sea Killed Thousands, Yet Its Story Is Little-Known. Why?

Ascomycete Life Cycle



Plasmogamy and mitosis: The ascogonium and antheridium fuse. Mitosis and cell division result in the formation of many dikaryotic hyphae, which form a fruiting body called the ascocarp. Asci form at the tips of these hyphae.

Karyogamy: The nuclei in the asci fuse to form a diploid zygote.

Meiosis: An ascus with four haploid nuclei is formed.

Mitosis and cell division: Eight haploid ascospores are formed.

1 Compatible hyphae mate by plasmogamy of hyphal branches, combining nuclei of 2 genetic types.

2 The mated cell produces a dikaryotic mycelium by mitotic division of both types of nuclei.

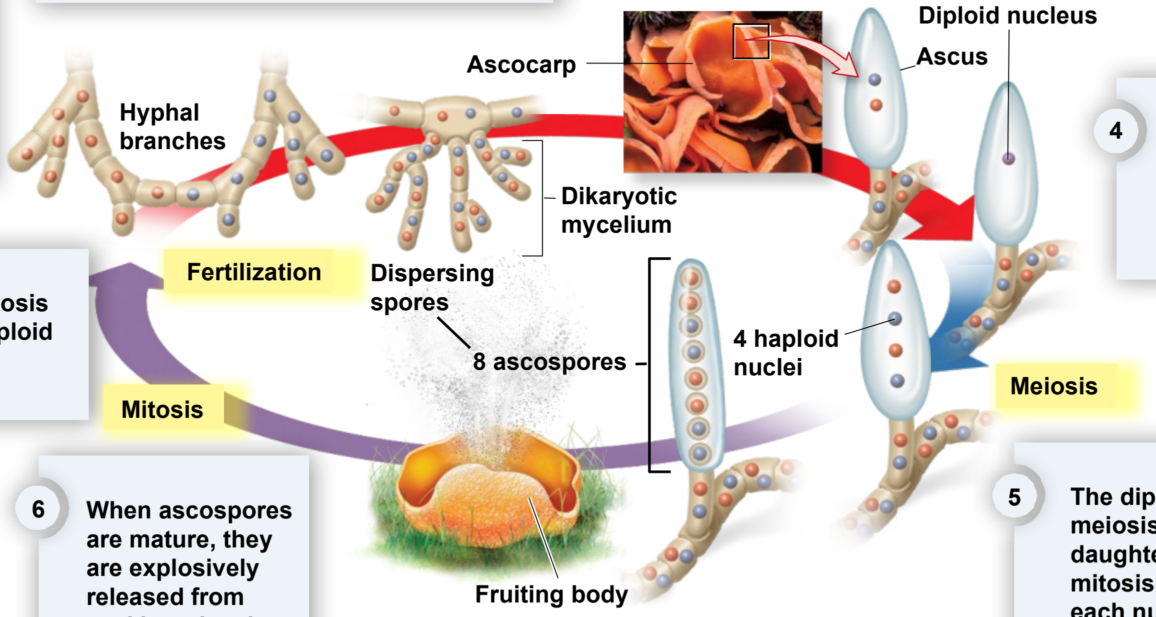
3 The dikaryotic mycelium produces a fuiting body known as an ascocarp. At the surface of the ascocarp, hyphae produce sac-shaped asci, each containing 2 haploid nuclei of distinct genotype.

4 The 2 nuclei fuse to form a diploid zygote nucleus in the process known as karyogamy.

5 The diploid nucleus undergoes meiosis, then each of the 4 haploid daughter nuclei divide again by mitosis. The cytoplasm around each nucleus secretes a spore wall, resulting in 8 ascospores.

6 When ascospores are mature, they are explosively released from asci into the air.

7 Ascospores grow by mitosis into hyphae having 1 haploid nucleus per cell.



KEY

🟪 Haploid

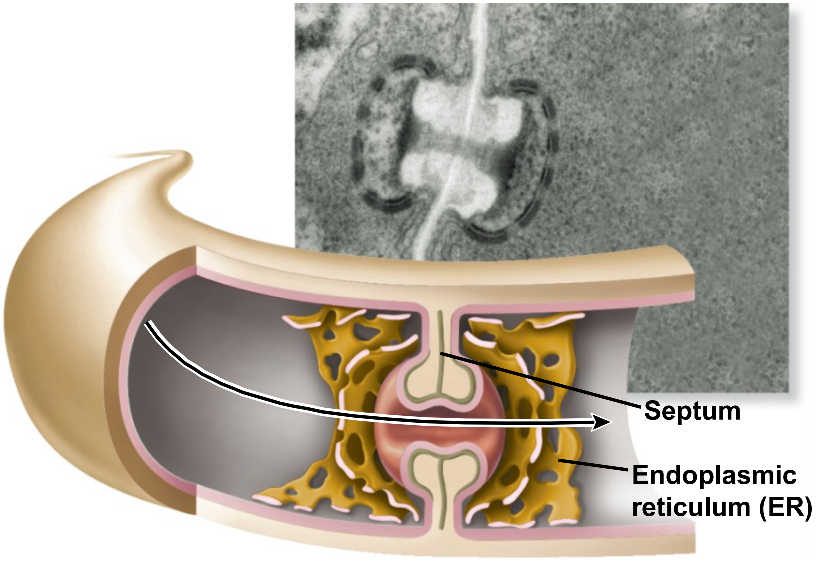
🟦 Diploid

🟥 Heterokaryotic

(b) Sexual reproduction of the ascomycete *Aleuria aurantia*

b(middle inset): © Ed Reschke/Getty Images

BASIDIOMYCOTA (CLUB FUNGI)



(b) Complex pore—basidiomycetes

b: © Charles Mimsz

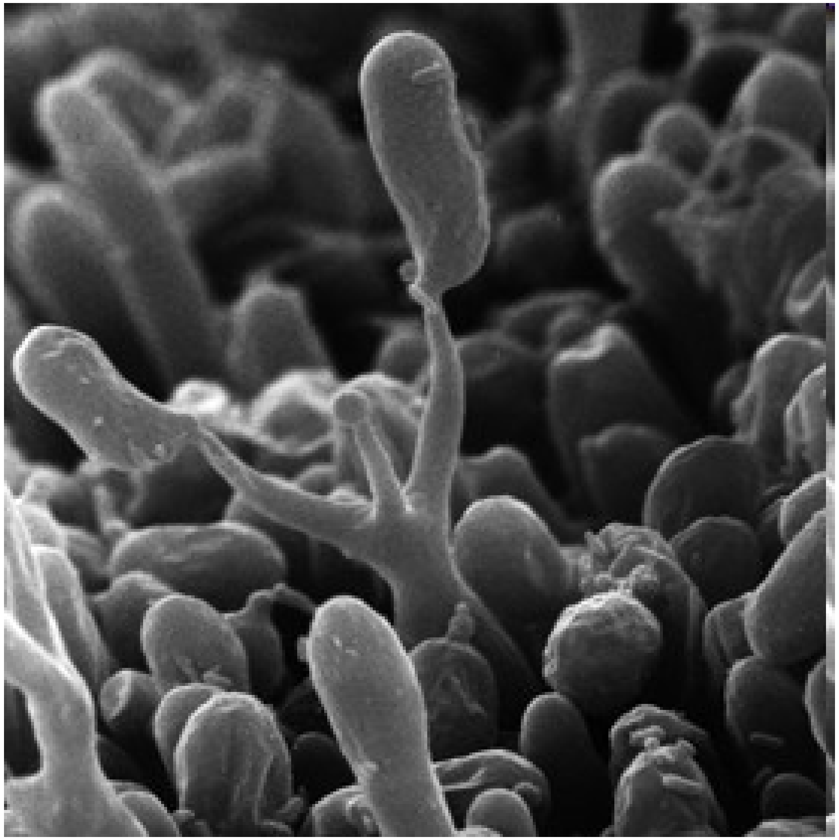
Hyphae subdivided by septa with complex septal pores

Important decomposers, plant pathogens, and mycorrhizal partners

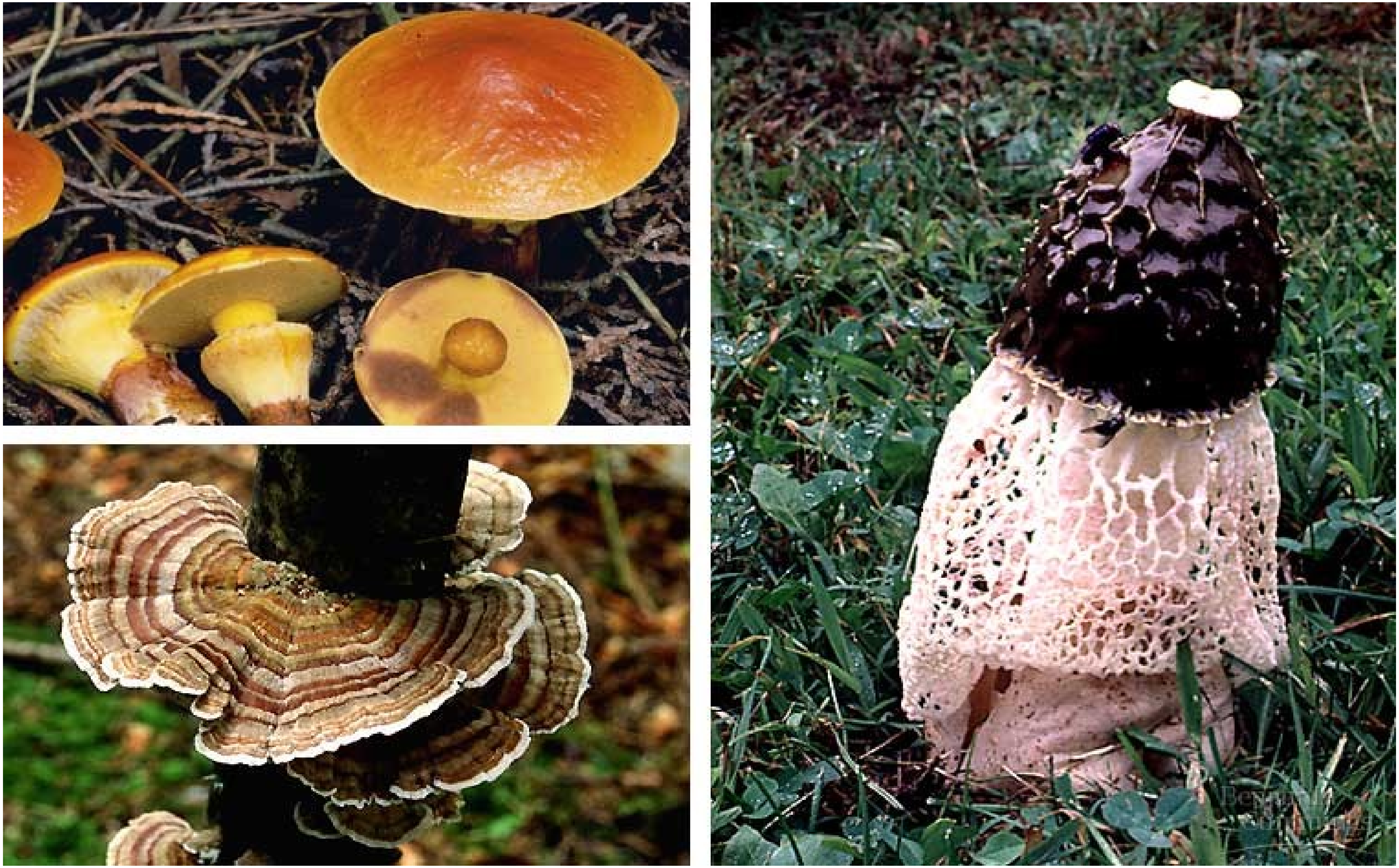
Produce mushrooms, puffballs, stinkhorns, shelf fungi, rusts and smuts as fruiting bodies

Named for **basidia** that produce sexual spores called **basidiospores**

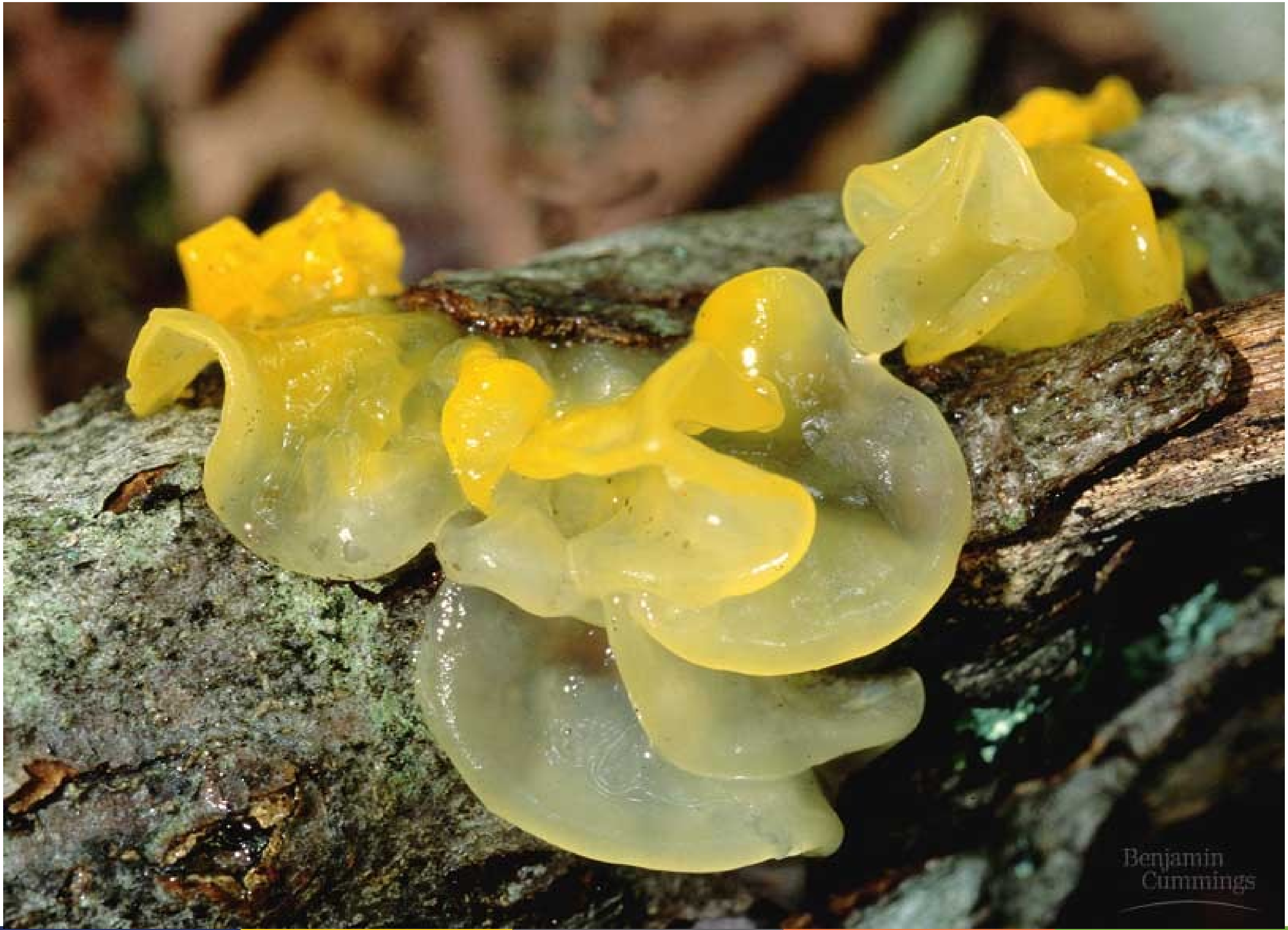
Fruiting bodies called **basidiocarps**

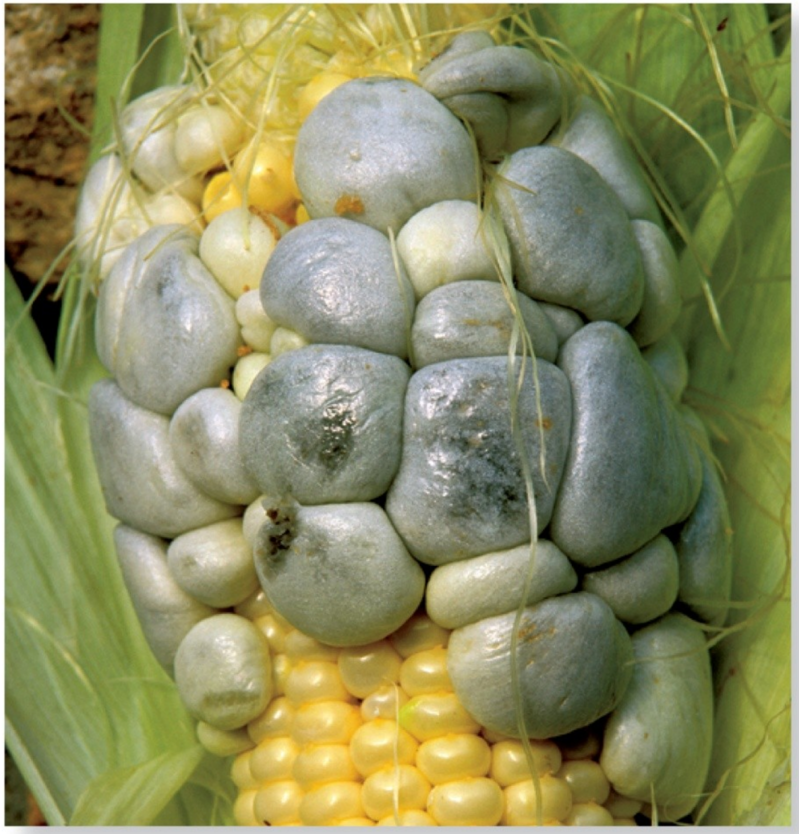


BASIDIOMYCETES (CLUB FUNGI): GREVILLE'S BOLETE (TOP LEFT), TURKEY TAIL (BOTTOM LEFT), STINKHORN (RIGHT)

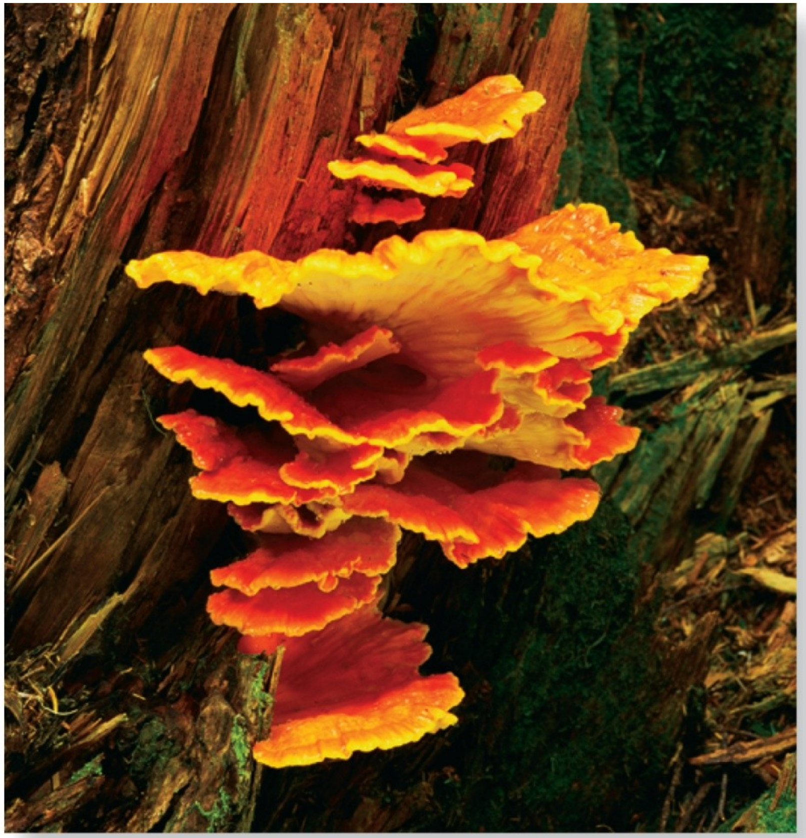


TREMELLA MESSENTERICA, WITCH'S BUTTER


Benjamin Cummings

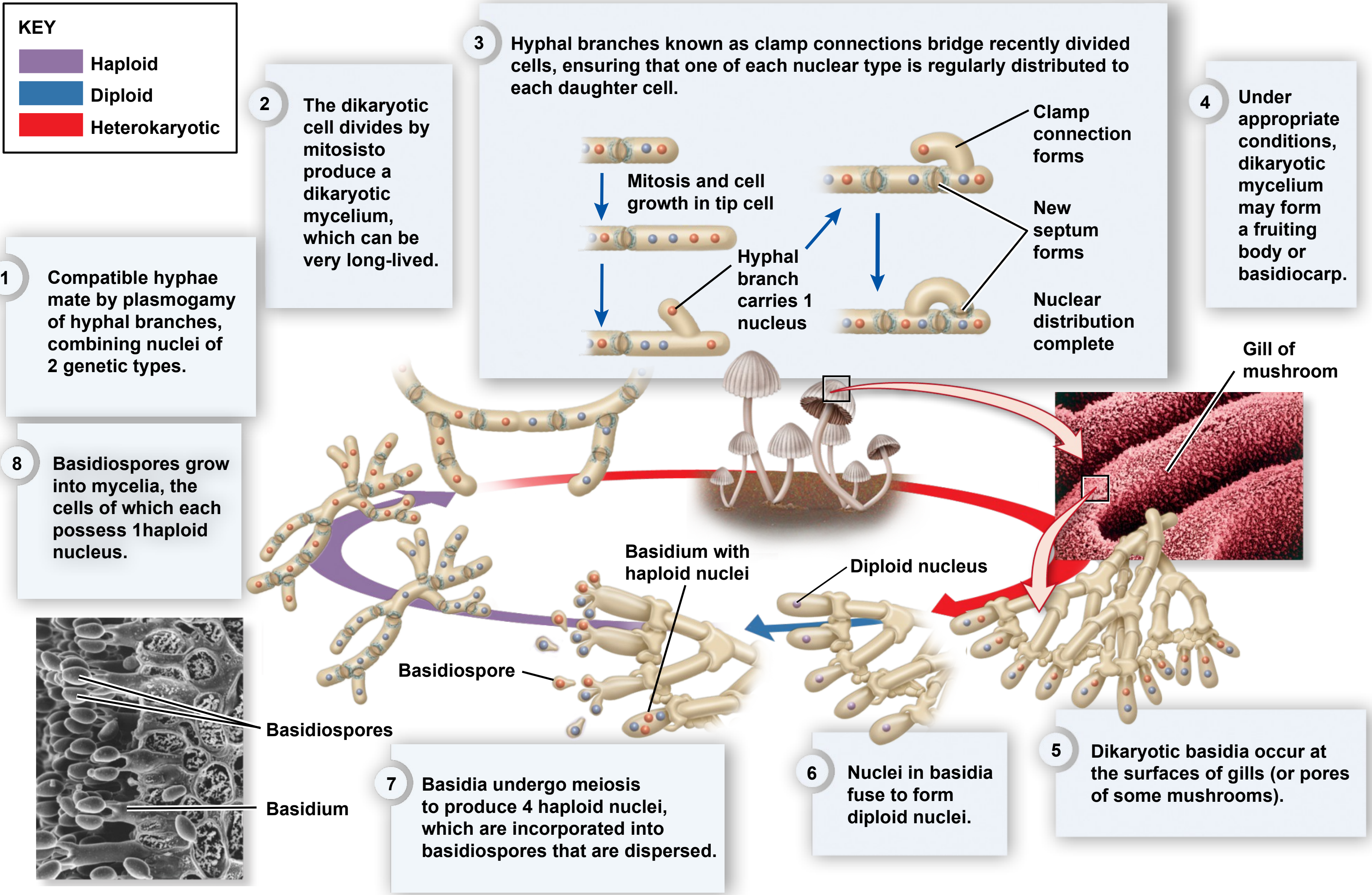


(a) Corn smut



(b) Shelf Fungi

a: © Dayton Wild/Visuals Unlimited; b: © Mark Turner/Botanica/Getty Images



KEY

- 🟪 Haploid
- 🟦 Diploid
- 🟥 Heterokaryotic

1 Compatible hyphae mate by plasmogamy of hyphal branches, combining nuclei of 2 genetic types.

2 The dikaryotic cell divides by mitosisto produce a dikaryotic mycelium, which can be very long-lived.

3 Hyphal branches known as clamp connections bridge recently divided cells, ensuring that one of each nuclear type is regularly distributed to each daughter cell.

Mitosis and cell growth in tip cell
Hyphal branch carries 1 nucleus
Clamp connection forms
New septum forms
Nuclear distribution complete
Gill of mushroom
Basidium with haploid nuclei
Diploid nucleus
Basidiospore
Basidiospores
Basidium

4 Under appropriate conditions, dikaryotic mycelium may form a fruiting body or basidiocarp.

5 Dikaryotic basidia occur at the surfaces of gills (or pores of some mushrooms).

6 Nuclei in basidia fuse to form diploid nuclei.

7 Basidia undergo meiosis to produce 4 haploid nuclei, which are incorporated into basidiospores that are dispersed.

8 Basidiospores grow into mycelia, the cells of which each possess 1haploid nucleus.

(right inset): © Dr. Jeremy Burgess/Photo Researchers, Inc.; (left inset): © Biophoto Associates/Photo Researchers, Inc.

Fungal Ecology and Biotechnology

Decomposer fungi are essential components of the Earth’s ecosystems

They work with bacteria

Only certain bacteria and fungi can break down cellulose

Release minerals to the soil and water

FUNGAL PATHOGENS

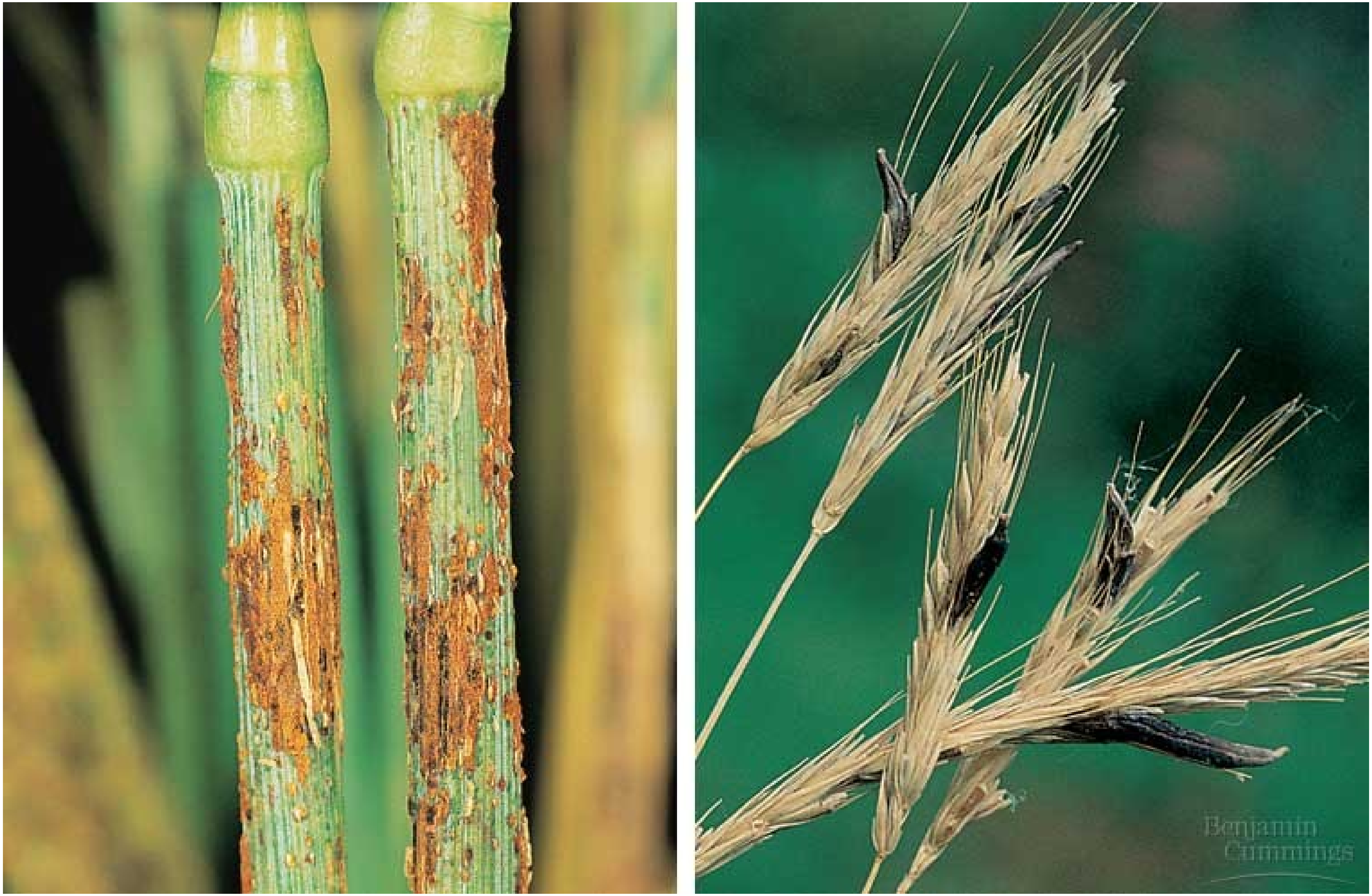
5000 species cause serious **crop diseases**

- Rust spores can be spread on the wind or by other means

Several **human diseases**

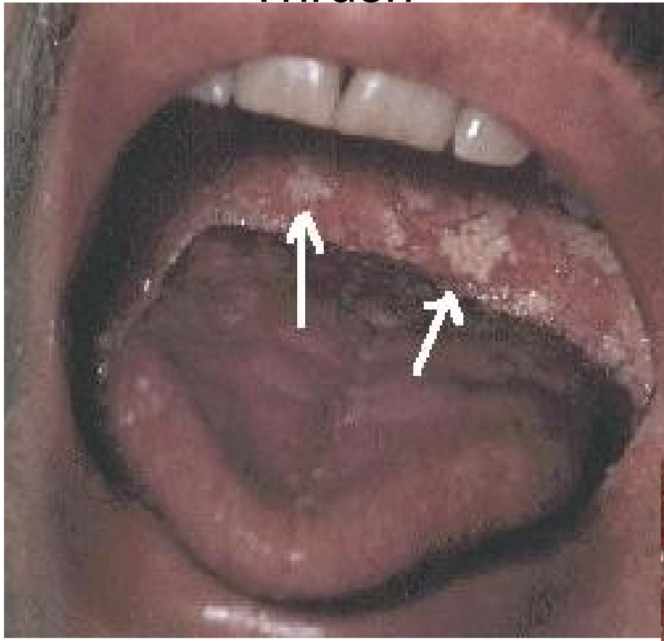
- Dermatophytes – athlete’s foot, ringworm
- *Pneumocystis carinii* pneumonia in AIDS
- Valley fever

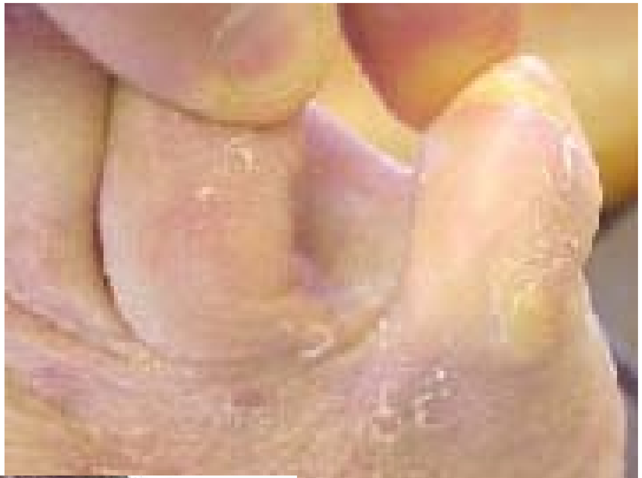
EXAMPLES OF FUNGAL DISEASES OF PLANTS: BLACK STEM RUST ON WHEAT (LEFT), ERGOTS ON RYE (RIGHT)



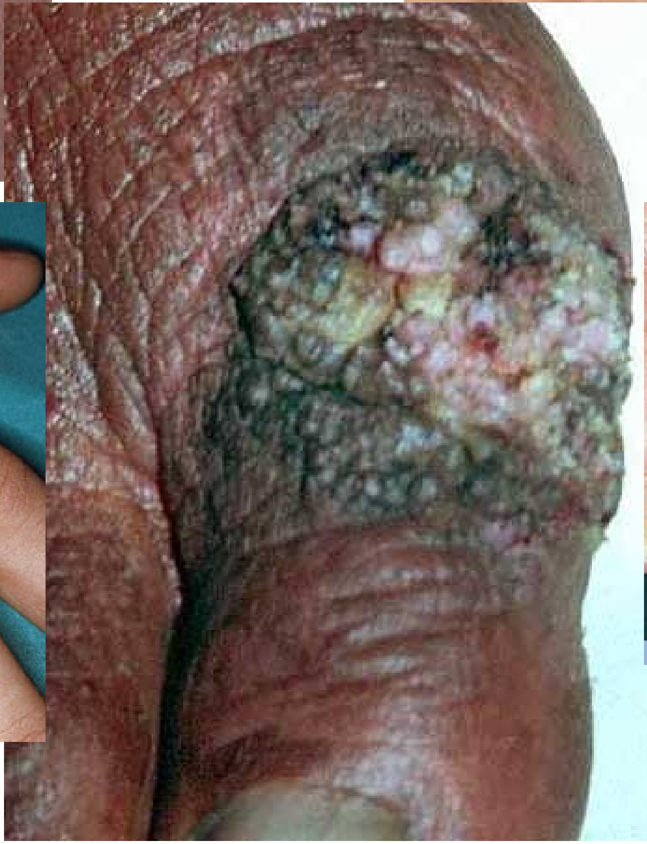
Benjamin Cummings

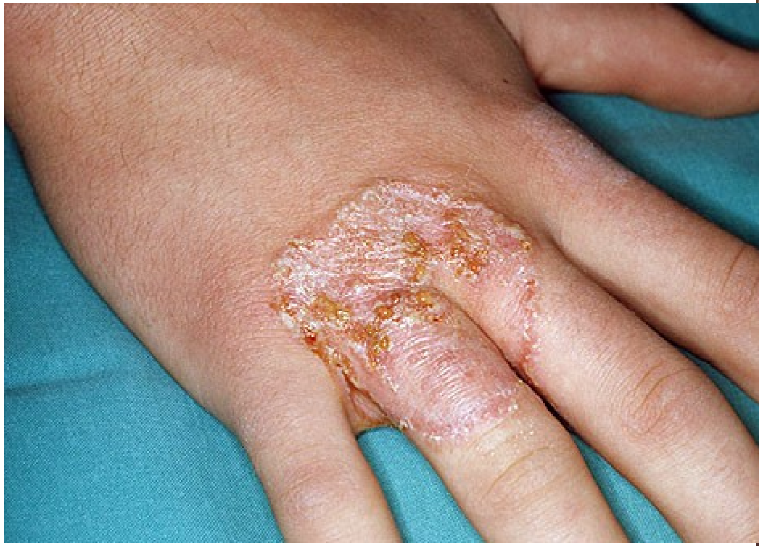
Thrush



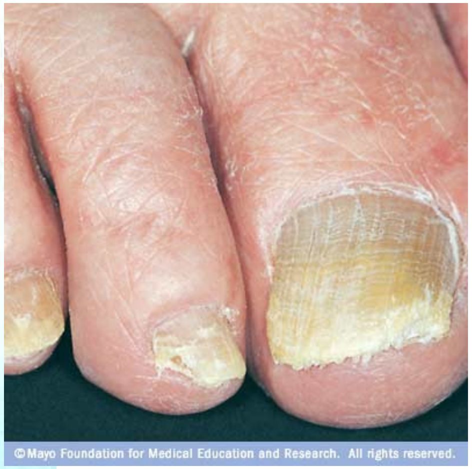


Athlete's foot





Ringworm

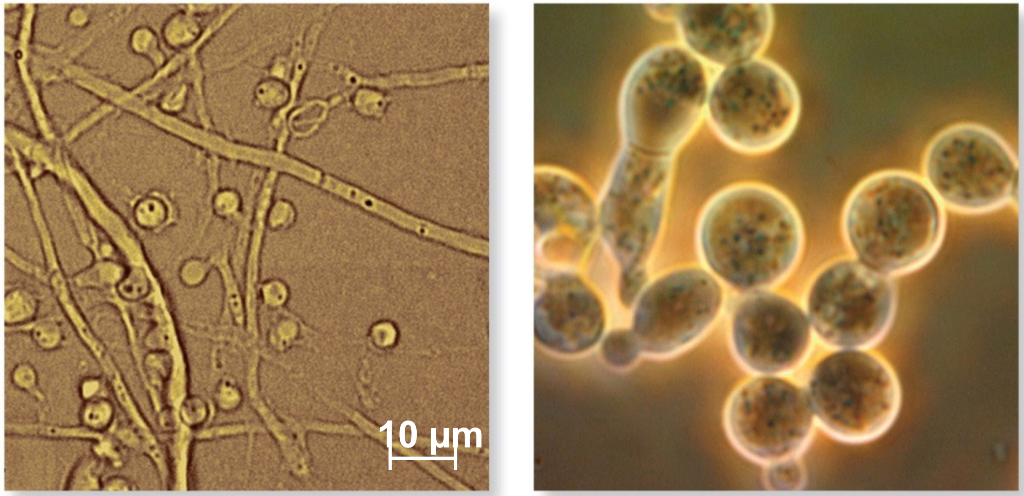


©Mayo Foundation for Medical Education and Research. All rights reserved.

Toenail fungus

COCCIDIOMYCOSIS – VALLEY FEVER

- **Causative agent – *Coccidioides immitis,* an Ascomycota fungus**
- **Endemic to the American Southwest and the San Joaquin Valley.**
- **Potentially fatal, particularly in immunocompromised patients**



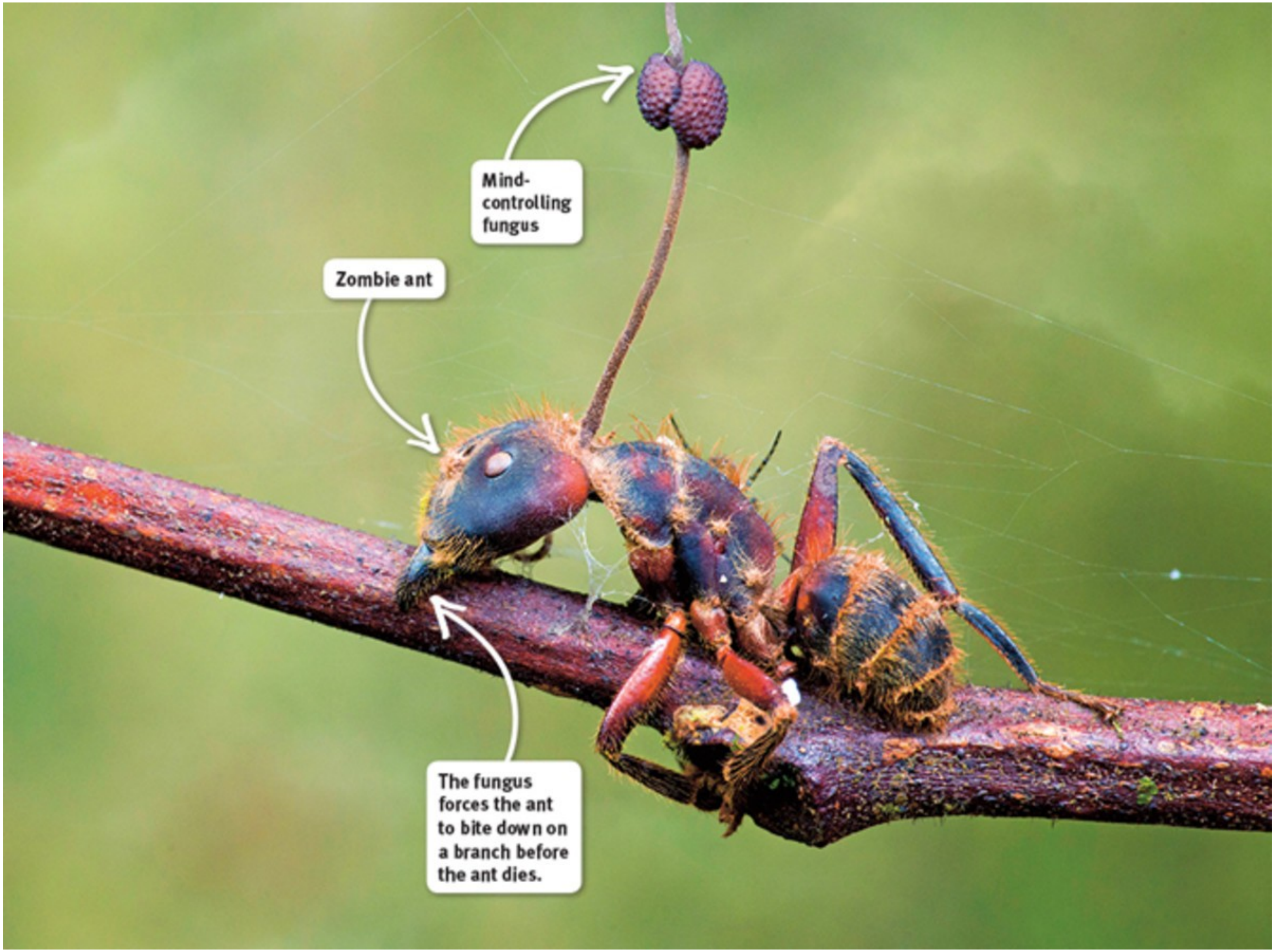
(a) Soil-dwelling hyphal phase **(b) Budding yeast phase in host**

a: Courtesy Bruce Klein. Reprinted with permission; b: Cover photograph of The Journal of Experimental Medicine, April 19, 1999, 189(8). Copyright © 1999 by The Rockefeller University Press

Dimorphic fungi (*Coccidioides)*

- Live as spore-producing hyphae in the soil
- Transform into pathogenic yeasts when mammals inhale their wind-dispersed spores
- Host body temperature triggers the change from hyphal to yeast form

ANIMAL PARASITISM BY FUNGI CORDYCEPS


Mind-controlling fungus
Zombie ant
The fungus forces the ant to bite down on a branch before the ant dies.

© melvyn yeo

© Daniel Winkler

www.DanielWinkler.com

orionmystery.blogspot.com

CORDYCEPS VIDEO

The Last of Us

FUNGAL ASSOCIATIONS WITH PHOTOSYNTHETIC PARTNERS

Associations with photosynthetic partners are mutualistic symbioses

Mycorrhizal fungi

Lichens

MYCORRHIZAE

Association between the hyphae of certain fungi and the roots of most seed plants

More than 90% of terrestrial plants have mycorrhizae

Plants receive increased supply of water and mineral nutrients

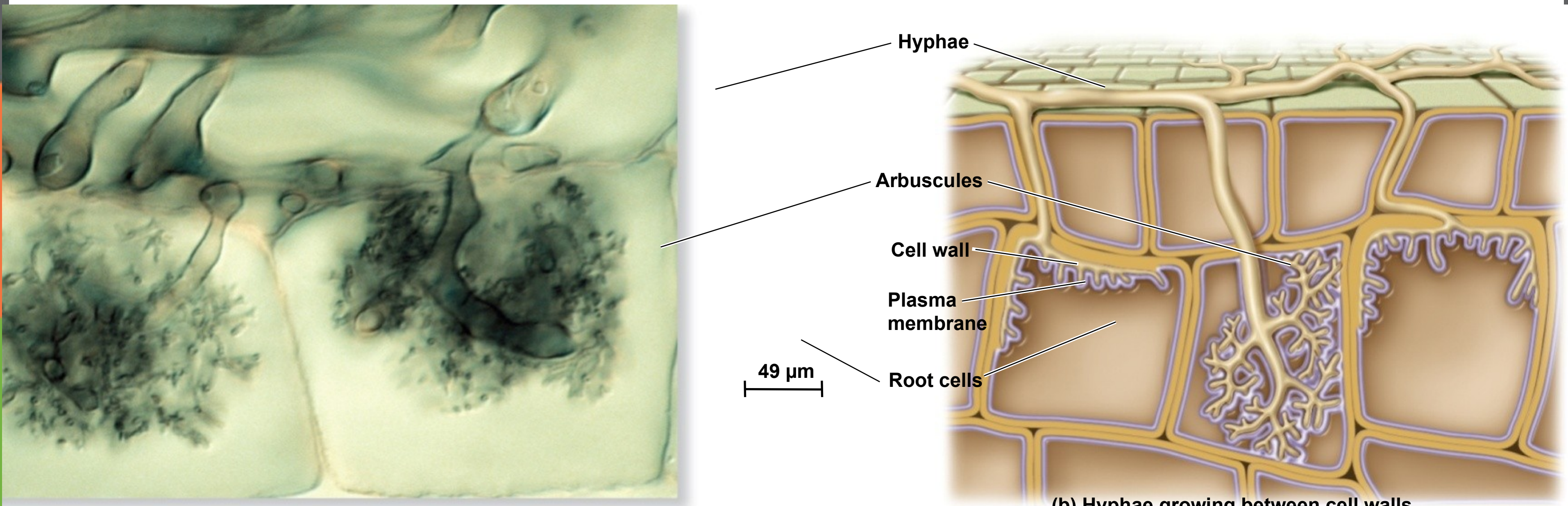
Fungi get organic food molecules (sugars) from the plants

Two most common types are **endomycorrhizae** and **ectomycorrhizae**

Endomycorrhizae

Fungal hyphae penetrate the spaces between root cell walls and plasma membranes and grow along the outer surface of the plasma membrane

- **Arbuscular mycorrhizae (AM)** form highly branched structures with high surface area
- Ability of early plants to live on land may have depended on help from endomycorrhizal fungal associations



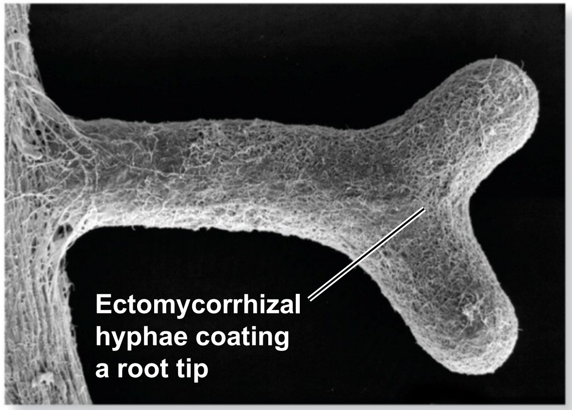
(a) Micrograph of arbuscular mycorrhizae

(b) Hyphae growing between cell walls and plasma membranes

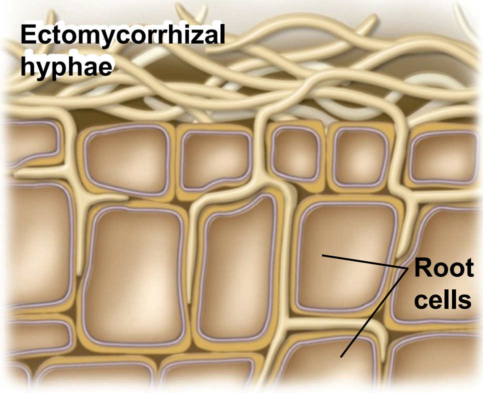
Ectomycorrhizae

- Coat root surface and grow between cells of roots
- Some species of oak, beech, pine, and spruce trees will not grow unless their ectomycorrhizal partners are also present
- Relationship is shared mostly by Ascomycota and Basidiomycota.

(a) Ectomycorrhizal fruiting body

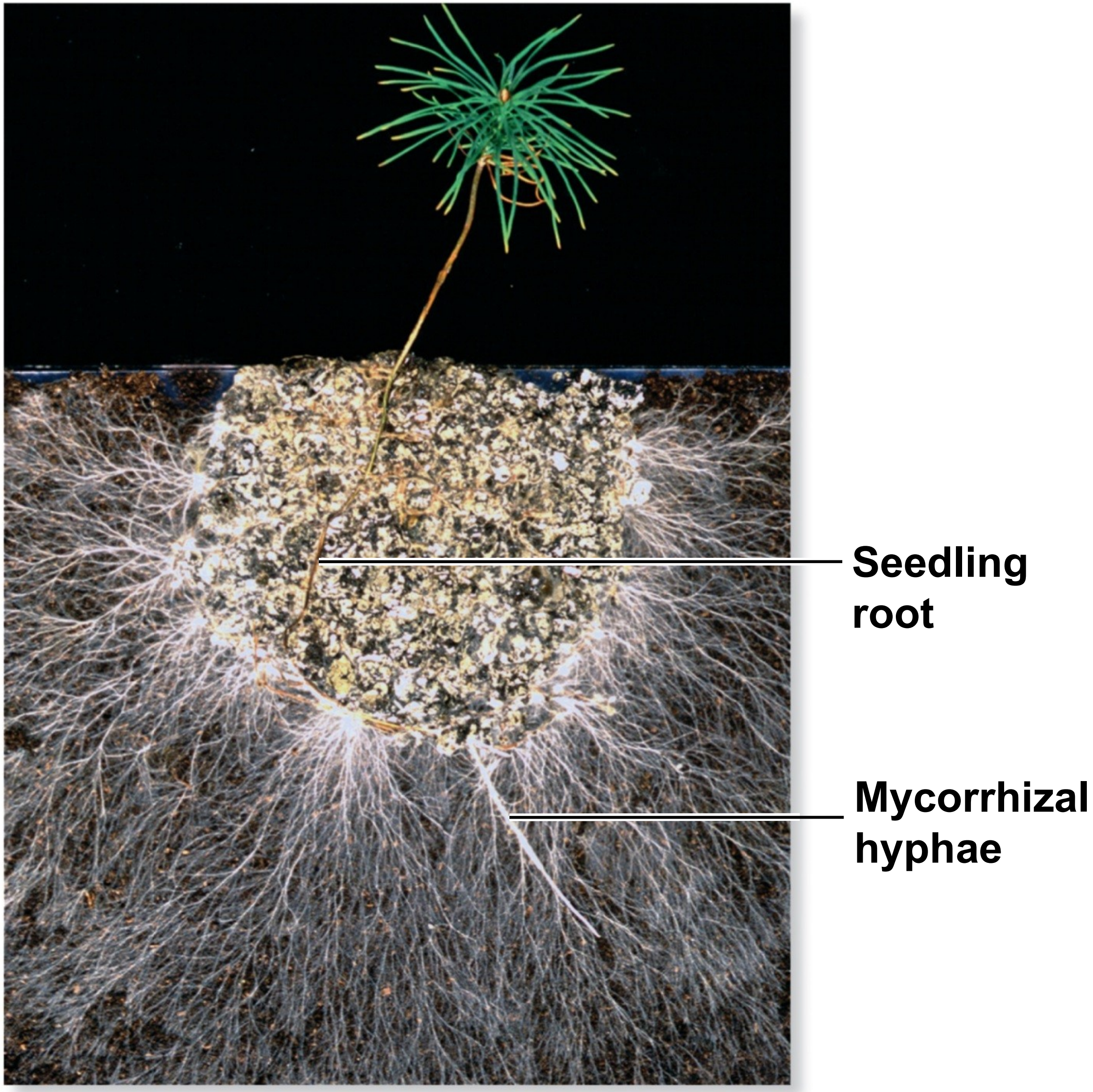


(b) SEM of ectomycorrhizal hyphae



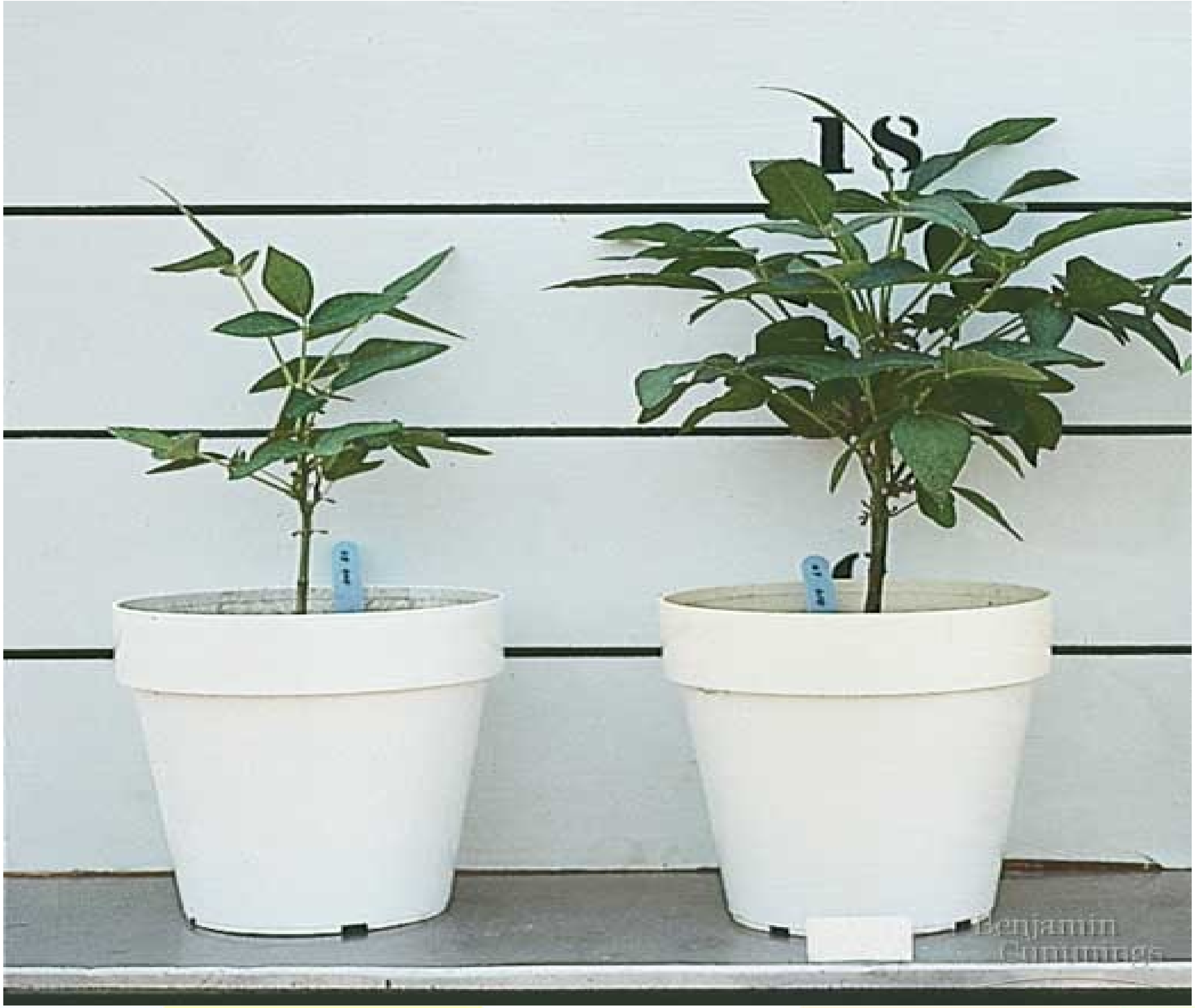
(c) Hyphae invading intercellular spaces

a: © Jacques Landry, Mycoquebec.org; b: © Courtesy of Larry Peterson and Hugues Massicotte



© Dr. D.P. Donelley and Prof. J.R. Leake, University of Sheffield, Department of Animal & Plant Sciences

AN EXPERIMENTAL TEST OF THE BENEFITS OF MYCORRHIZAE



LICHENS

Partnerships of particular **fungi** and certain photosynthetic **green algae** and/or **cyanobacteria**

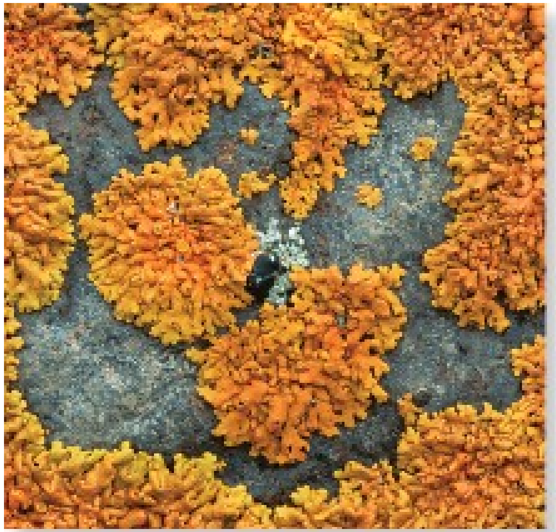
25,000 lichen “species”

- ☐Not all descended from a common ancestor
- ☐At least **five separate fungal lineages**

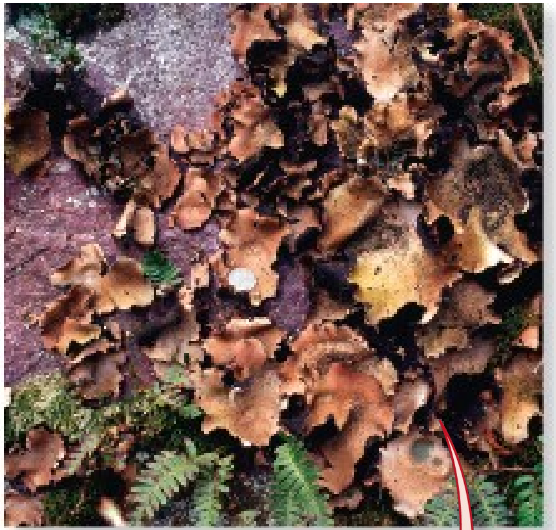
Three major forms – **crustose, foliose, fruticose**

Photosynthetic partner provides organic food molecules (sugar) and oxygen

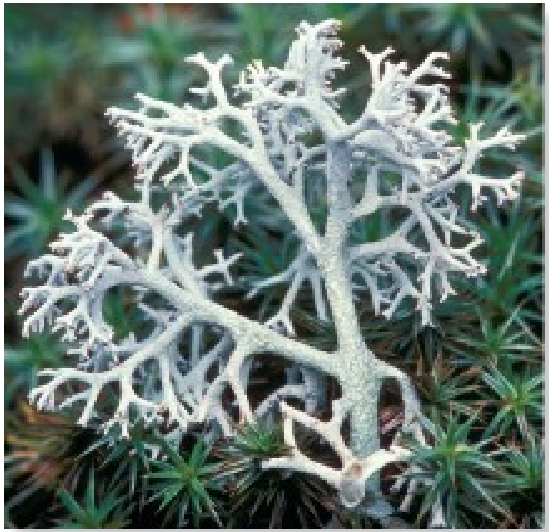
Fungal partner provides carbon dioxide, water, and minerals



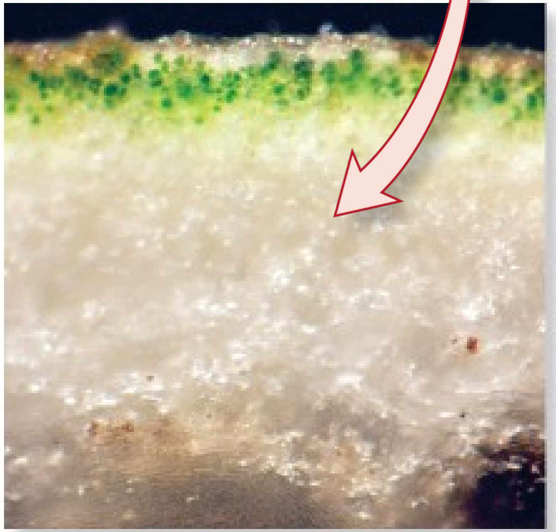
(a) Crustose lichen



(b) Foliose lichen



(c) Fruticose lichen



(d) Microscopic view of a cross section of a lichen

a: © Joe McDonald/Corbis; b: © Lee W. Wilcox; c: © Ed Reschke/Getty Images; d: © Lee W. Wilcox

BIOTECHNOLOGY APPLICATIONS

Fungi convert inexpensive organic compounds into **citric acid, glycerol,** and **antibiotics**

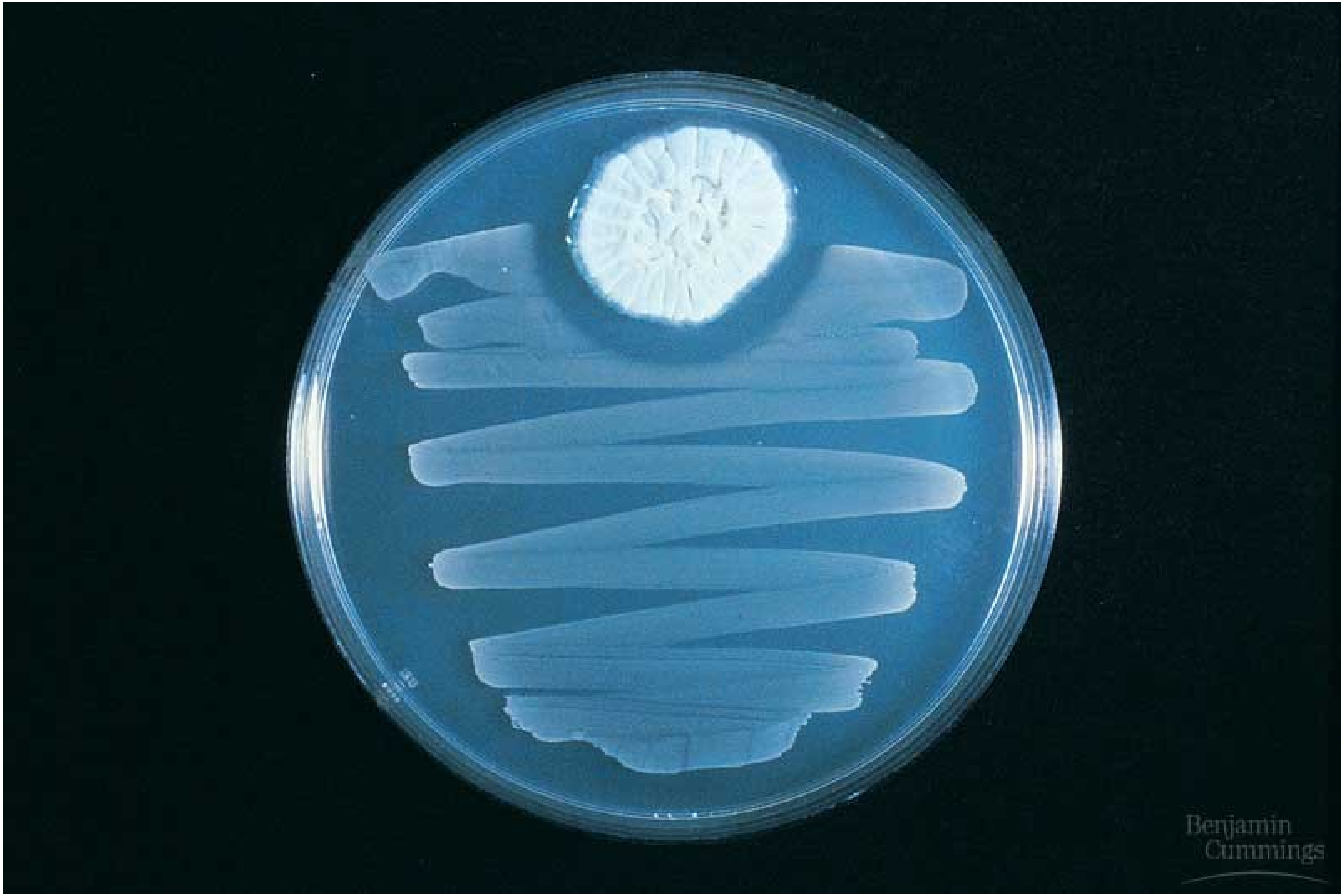
Distinctive flavor of **blue cheese**

Saccharomyces cerevisiae for **bread, beer** and **wine**

Replace chemical procedures that generate harmful waste products

- Wood pulp bleaching

FUNGAL PRODUCTION OF AN ANTIBIOTIC

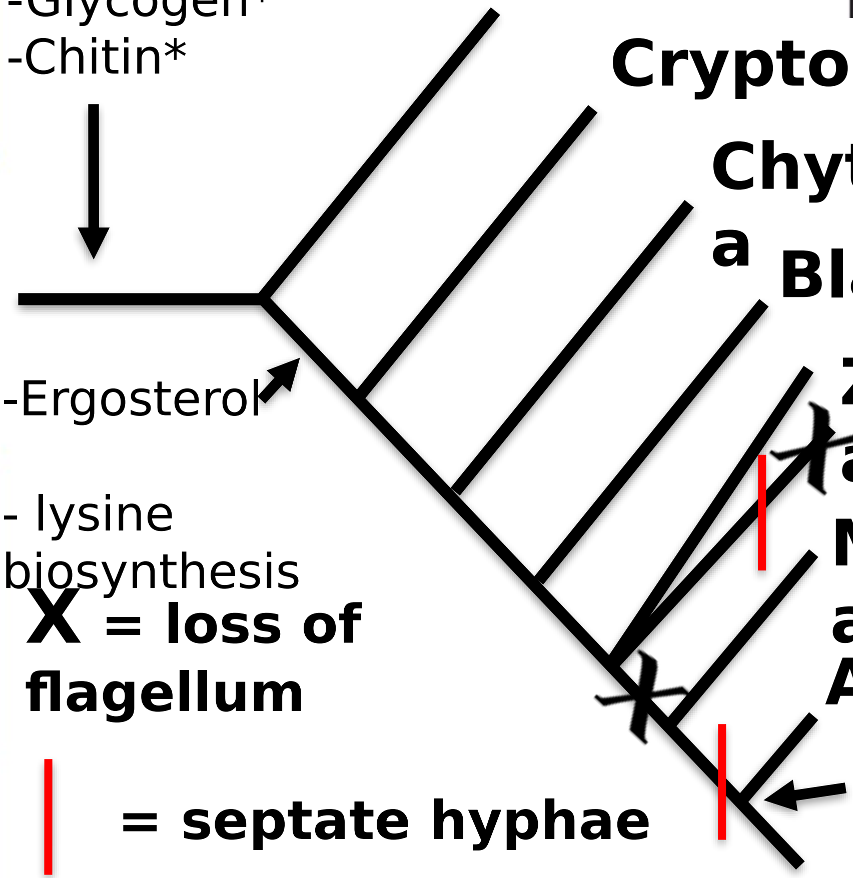


Benjamin Cummings

Some clinically important antibiotics

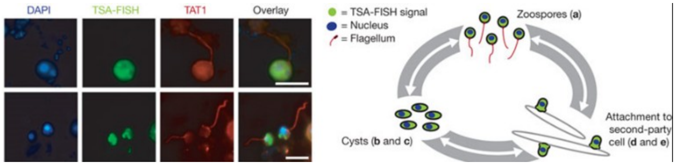
Antibiotic	**Producer organism**	**Activity**	**Site or mode of action**
Penicillin	*Penicillium chrysogenum*	Gram-positive bacteria	Wall synthesis
Cephalosporin	*Cephalosporium acremonium*	Broad spectrum	Wall synthesis
Griseofulvin	*Penicillium griseofulvum*	Dermatophytic fungi	Microtubules
Bacitracin	*Bacillus subtilis*	Gram-positive bacteria	Wall synthesis
Polymyxin B	*Bacillus polymyxa*	Gram-negative bacteria	Cell membrane
Amphotericin B	*Streptomyces nodosus*	Fungi	Cell membrane
Erythromycin	*Streptomyces erythreus*	Gram-positive bacteria	Protein synthesis
Neomycin	*Streptomyces fradiae*	Broad spectrum	Protein synthesis
Streptomycin	*Streptomyces griseus*	Gram-negative bacteria	Protein synthesis
Tetracycline	*Streptomyces rimosus*	Broad spectrum	Protein synthesis
Vancomycin	*Streptomyces orientalis*	Gram-positive bacteria	Protein synthesis
Gentamicin	*Micromonospora purpurea*	Broad spectrum	Protein synthesis
Rifamycin	*Streptomyces mediterranei*	Tuberculosis	Protein synthesis

Fungal Phylogeny



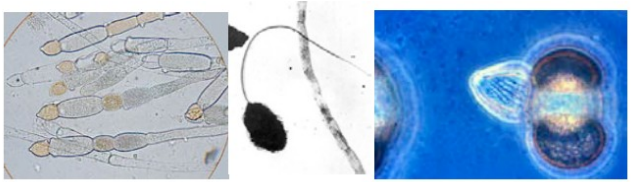
-Smooth flagellum*
-Flat mito. cristae*
-Glycogen*
-Chitin*

Animals



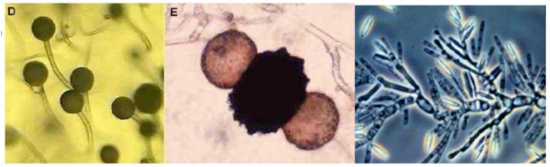
Cryptomycota

Chytridiomycota

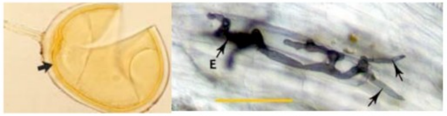


Blastocladiomycota

Zoopagomycota

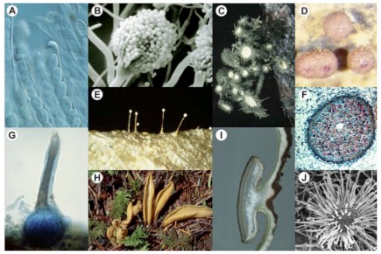


Mucoromycota

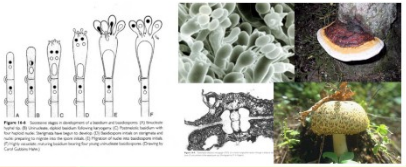


Ascomycota

-Regularly septate hyphae
-Complex sporocarps



Basidiomycota



-Ergosterol

- lysine biosynthesis

X = loss of flagellum

| = septate hyphae

*** = shared with animals**